The Association

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Engineering and Shipbuilding Draughtsmen

THE DESIGN OF SHIP'S LINES AND CONSIDERATION ON FORM AND RESISTANCE.

R. ALLAN, B.Sc., (Foreign Member).

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SESSION 1928-29.

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THE DESIGN OF SHIP'S LINES AND CONSIDERATIONS ON FORM AND RESISTANCE.

By R. ALLAN, B.Sc. (Foreign Member).

The original article was read before the Newcastle Branch in 1918, and was printed. The present pamphlet is a revised edition. The matter has been brought up to date and extended.

Published by The Technical Section, Association of Engineering and Shipbuilding Draughtsmen, 96 St. George's Square, London, S.W. 1.

SESSION 1928-29.

MILNE, TANNAHILL, & METHVEN, 12-14 Mill Street, Perth.

PREFACE.

LAST Session, 1917-18, two of our members, Messrs. Steele and Larkin, read before this Branch a very interesting paper on the determination of ship proportions and machinery dimensions. That paper, to a large extent, dealt with the fixing of the dimensions to carry a certain specified deadweight. In it the lines and sectional area curve were briefly mentioned. Starting from this point, it is proposed to discuss in detail, in the first portion of this work, various methods of constructing body plans from previous successful designs; and, in the second portion, to examine the latest model experiment tank results for guidance in the choice of the best possible sectional area curve and proportions for specified conditions. This work is primarily intended for shipbuilders, but the second portion, which necessarily will largely deal with resistance, should interest engineers. To properly design ship lines, the sectional area curve should be first fashioned, but in nine cases out of ten in ordinary practice, the new design is constructed from some previous successful design, or, in many cases I am afraid, from a supposedly successful one. For this reason, Part I. should prove of interest to the ordinary draughtsman, whilst Part II. will, at least, draw his attention to the more technical side of the subject.

R. ALLAN.

October, 1918.

THE DESIGN OF SHIP'S LINES AND CONSIDERATIONS ON FORM AND RESISTANCE

By R. ALLAN, B.Sc. (Foreign Member).

PART I.

DESIGN.

I.—Graphical method of constructing body plan to give a required displacement, having same coefficients as previous design, *i.e.*, same block, mid-area and prismatic coefficients.

The usual method is to set off new water-lines in the ratio of the draughts, and alter the half-breadths in the ratio of the breadths, a simple but rather laborious task. In the graphic method this work can be accomplished in a very few minutes.

Method of Procedure.—Draw the outline body plan half-breadth, base, and load water-line for the new design on transparent paper or tracing cloth. Then draw in water-lines corresponding to the water-lines of the basis ship at a distance apart given by original spacing multiplied by draught of new ship divided by draught of basis ship.

(*a*) Beam of new ship greater than beam of basis ship.

(See Plate No. 1).

To obtain the offsets for any given water-line, say W_1, L_1, place the new body plan outline over the basis ship body plan so that points O on corresponding water-lines coincide, then slew upper plan round until the half-breadth spot W_1 on the new design lies on the half-breadth line W_1W of the basis ship as shewn. Project down the various water-line spots of the basis ship as at R, S, B etc., on the water-line W_1L_1 by lines RR_1, SS_1, BB_1, etc., parallel to W_1W on the new design.

(*b*) Beam of new ship smaller than beam of basis ship.

The process is very similar to above, except that the body plan of basis ship is placed in the inclined position, and the new design

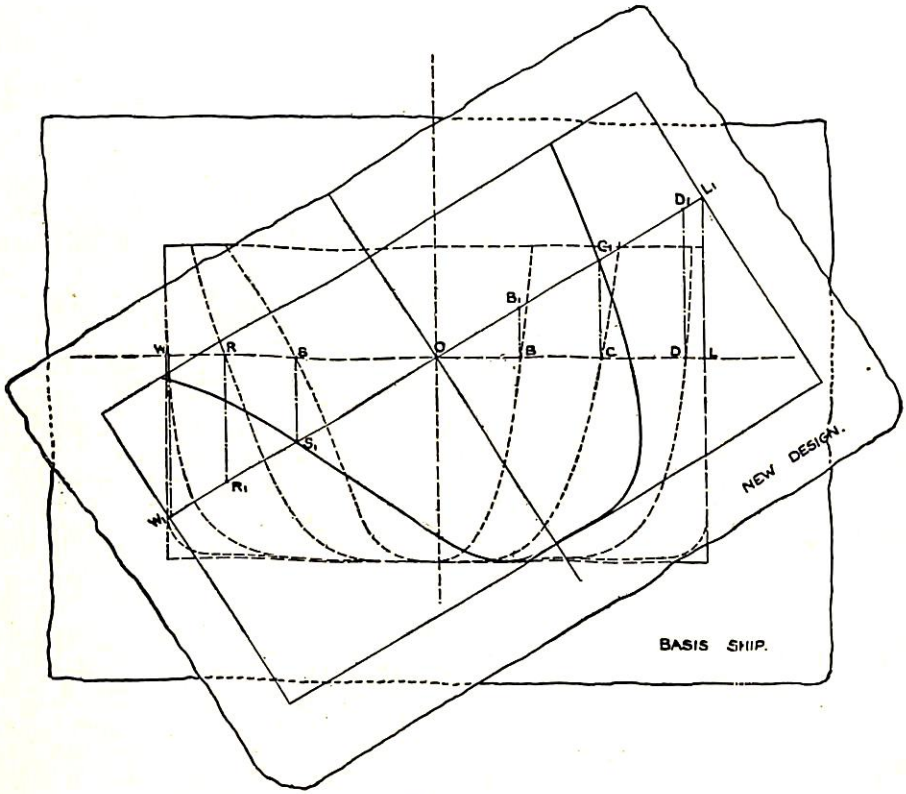


PLATE 1.

placed over it, so that spot W of basis ship lies on the half-breadth line WW_1 of the new design. Then project up or down spots as before. Repeat process for each water-line, shifting upper body plan each time so that centre line intersections of corresponding water-lines coincide. To obviate shifting for each water-line, spots on water-lines other than W_1L on basis ship may be projected parallel to WW_1 on to W_1L_1, and then squared down on to the corresponding inclined water-line of the new design.

The principle of the method is based on the properties of similar triangles, the offsets of the basis ship being expanded or contracted in the exact proportion required.

After a little familiarity with the process, a complete fair body plan may be obtained in from 30 minutes to one hour.

Plate No. 2 illustrates another graphical method of solving the same problem.

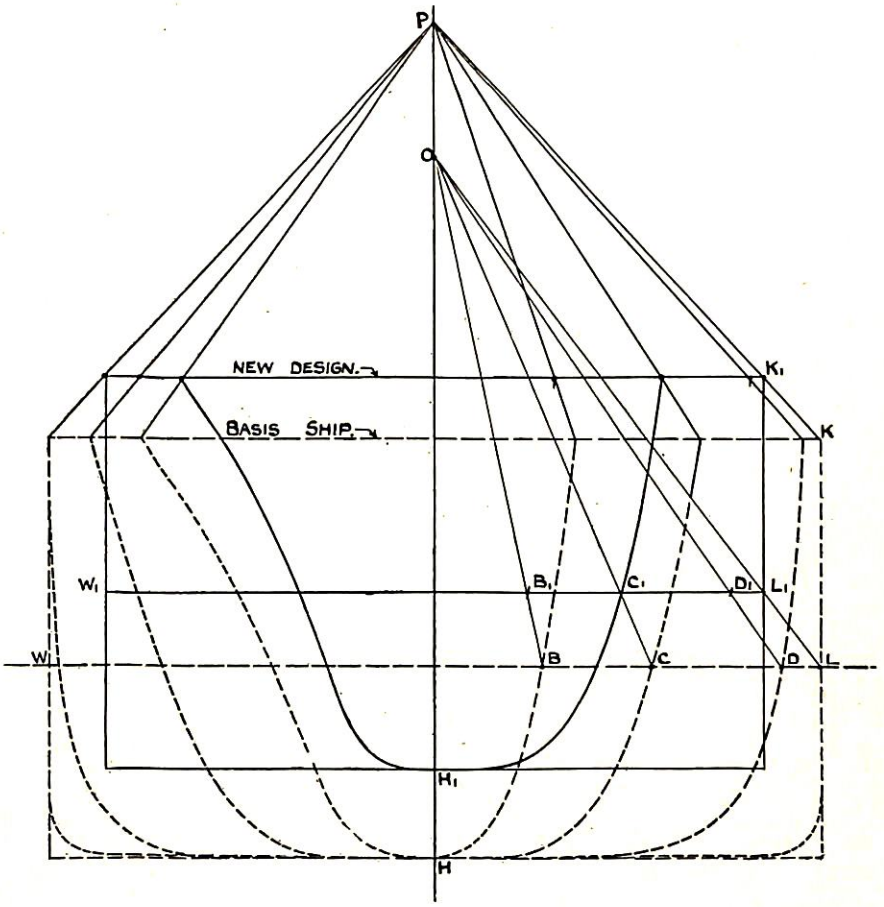


PLATE 2.

Proceed as before. The new outline body plan is placed over the basis ship body plan with the centre lines coinciding, so that corresponding waterlines WL and W_1L_1 are clear of each other by any convenient distance. To obtain spots on W_1L_1 for new design join the spots LL_1 by a line which meets the centre line at O. Join OB, OC, OD, etc., to cut W_1L_1 in B_1, C_1, D_1, etc., respectively, which will be the spots required. For convenience in drawing the angle WLO should be about 45 degrees. If the upper body plan be placed over the basis ship body plan so that the corresponding water-lines all clear each other, and so that lines OL, PK, etc., are at about 45 degrees to the centre line, then the whole of the spots for the new design may be obtained in a few minutes.

II.—Graphical method of constructing body plan to give a required displacement, keeping the same form of sectional area curve as previous design.

This problem is particularly applicable to the design of destroyers, cruisers, Channel steamers, etc., where the sectional area curve has been found a very good one. Displacement and draft being fixed, and therefore block coefficient, by simply modifying the mid-area coefficient, the same prismatic, or in other words, the same sectional area curve, can thus still be adhered to.

Take an illustrative example.

Suppose the basis ship to have the following coefficients, viz. :—

Block coefficient,	...	...	·60
Mid area ,,	...	...	·88
Prismatic ,,	...	...	·682

and block of new ship ·59. Therefore mid-area to keep same prismatic must be $\frac{\cdot 59}{\cdot 682} = \cdot 865$.

Method of Procedure.—Design midship section to the desired shape and coefficient. Then space off water-lines corresponding to the water-lines on the basis ship's body plan in the proportion of $\frac{K_1 D_1}{K D}$ See Plate 3.

$$e.g.,\ K_1W_1 = \frac{K W \times K_1 D_1}{K D}$$

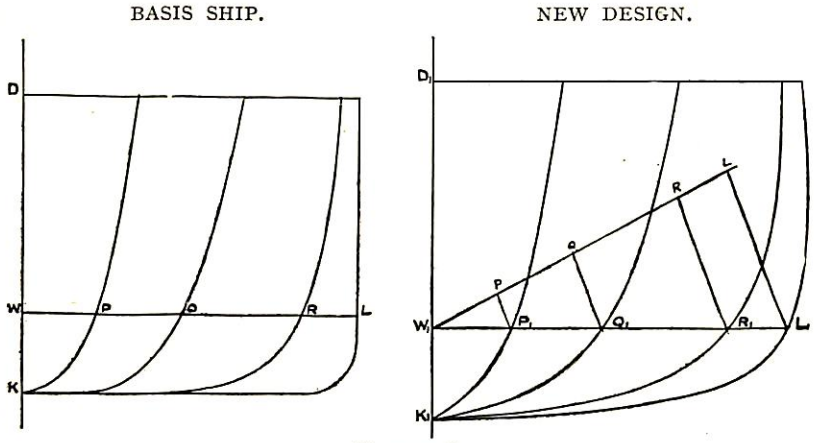


PLATE 3.

To find spots for W_1L_1 corresponding to WL in basis ship, alter the offsets of the basis ship in the proportion $\frac{W_1L_1}{WL}$, *i.e.*,

$$\frac{W_1P_1}{WP} = \frac{W_1Q_1}{WQ} = \underline{\quad\ldots\quad} = \frac{W_1L_1}{WL} \text{ or } W_1P_1 = \frac{WP \times W_1L_1}{WL} \text{ etc.}$$

Note that offsets for any given water-line are altered in the proportion of the corresponding half-breadths of that water-line at the midship sections, not in the proportion of the half-beams of the ships, as was done in methods (1) and (2).

The proportioning may be quickly performed graphically as shewn in sketch, offsets WP, WQ, WR, WL, etc., being transferred on to the new body plan by means of a strip of paper and parallel lines drawn as indicated.

It should be noted that in all the above graphical methods success depends on careful draughtsmanship to ensure exact proportioning. The graphical methods will be found quite as accurate as, and quicker than, the ordinary method of proportioning by using a slide rule or calculation.

III.—Construction of body plan to give a required displacement and specified position of centre of buoyancy by geometrical variation of the lines of previous design, when limits of parallel body suitable.

NUMERICAL EXAMPLE.

	Basis Ship.	Proposed Ship.
Length B.P., ...	400 ft. = L	422 ft. = L_1
Breadth, ...	52 ft. = B	54 ft. = B_1
Draught, ...	25 ft. = d	26 ft. 6 in. = d_1
Block coefficient, ...	·760 = C	·775 = C_1
Mid-area ,, ...	·990 = M	·990 = M
Prismatic ,, ...	·767	·783
Centre of Buoyancy,	3·5 ft. forward	2·5 ft. forward

It will be noticed that the mid-area coefficient is the only item that is the same in the two designs.

Proceed as follows :—

Find the block coefficients of the fore and aft bodies of each design respectively (a formula for this is given in the second part of paper).* For the basis ship they are ·779 forward and ·741 aft,

* See Appendix B.

and for new design ·789 forward and ·761 aft. Then, treating each end as a separate ship, we find the alteration to the parallel body as follows :—

Take fore body first.

Alteration of length of parallel body x,

$$= \frac{\text{difference of blocks} \times \frac{L}{2}}{\text{M—block of new ship}}$$

Thus the increase in length of parallel body in fore body

$$= \frac{(\cdot 789 - \cdot 779) \times 200}{\cdot 99 - \cdot 789} = 10 \text{ feet.}$$

$$\text{In after body} = \frac{(\cdot 761 - \cdot 741) \times 200}{\cdot 99 - \cdot 761} = 17 \text{ ft. } 5 \text{ in.}$$

The form having dimensions 200 ft. + 10 ft. and 52 ft. breadth, *i.e.*, 210 ft. and 52 ft. is next expanded to 211 ft. and 54 ft., so that all longitudinal dimensions are expanded in the ratio of $\frac{211}{210}$ and all transverse dimensions in the ratio of $\frac{54}{52}$. Therefore, setting off, starting from fore perpendicular sections 21 ft. apart on basis lines and lifting offsets, expand these in the ratio of $\frac{54}{52}$ setting off on water-lines which have been altered in the ratio of $\frac{d_1}{d}$, we get the fore-end sections. A similar procedure will obtain the after-end sections.

Another method of solving problem III., which has the advantage of being graphical, is as follows :—

Construct the body plan from basis body plan by method as explained in No. 1, whose breadth will be 54 ft. and draught 26 ft. 6 ins. Then for fore body set off, starting from the fore perpendicular, on half-breadth of new ship, sections whose distance apart are $\frac{211}{210} \times 40 = 40 \cdot 19$ ft., and for after body, starting from after perpendicular, distances apart of $\frac{211}{217 \cdot 4} \times 40 = 38 \cdot 82$ ft. Set off the sections before obtained at these spacings. Then lift offsets at the usual spacing of 42·2 feet apart, obtaining sections for new body plan.

IV.—Method of modifying sectional area curve to obtain a desired position of centre of buoyancy.

Suppose that a sectional area curve from a previous successful design has been obtained, but the position of the centre of buoyancy so obtained is not suitable for a new design. By altering the curve of areas, preferably in the after body, the necessary modification to the position of the centre of buoyancy may be obtained. As a rule it is better not to have too large a shift forward, since propulsion is much more sensitive to any alteration to the fore body, especially at moderate or high speeds. This is conveniently effected by shifting, *e.g.* aft, the midship section through a distance

$$h = \frac{d}{\left(1 - \frac{2k}{L}\right)}$$

Where d is the shift aft of centre of buoyancy desired, and k the distance between the centres of gravity of forward and after portions of the original curve of areas, varying from ·3L in low prismatics to ·4L in high. The positions of the perpendiculars remain unaltered, but the fore body is uniformly stretched and the after body contracted, the shift of any section originally distant x from amidships being $h - \frac{2xh}{L}$, L being the length between perpendiculars.

Part II.

FORM OF SECTIONAL AREA CURVE AND PROPORTIONS.

In the second part of this work it is intended to deal in detail with the question of the best form for specified conditions. Within recent years the knowledge of the effect of form on resistance has been greatly added to by such able experimenters as Froude, Taylor, Baker and Sadler. Mr. Froude's experiments have been mainly on fine high-speed vessels of the cruiser or Cross-Channel type. For solving the problems connected with the cargo vessel, Mr. Baker's results are perhaps the most extensive and suitable, though Sadler in America has also to a certain extent covered this field. Taylor's standard series and his experiments on the most suitable length of parallel body are also well worth study.

Cruiser and Cross-Channel Steamer Type of Curve. (No parallel body).

Mr. Froude published his results in the *Trans. I.N.A.* in 1904. To properly understand them a knowledge of the Froude system of notation is necessary. The father of the present Mr. Froude devised a method of eliminating absolute size from the comparison of resistances of various forms, based upon the three variables—displacement, resistance and speed. The value of speed which he called K is related to $\triangle^{\frac{1}{6}}$, and the value of resistance called C is related directly to displacement $\triangle$, and is really an inverted Admiralty coefficient. As an explanation of how these various constants are derived can be found in any text book on resistance, they are merely stated here.

V is speed in knots.
$\triangle$ is displacement in tons salt water.
L is length in feet between perpendiculars.
S is wetted skin area in square feet.

(1) The speed constant $K = \frac{V}{\triangle^{\frac{1}{6}}} \times \cdot 5834.$

(2) The resistance constant $C = \frac{E\,H\,P}{\triangle^{\frac{2}{3}} \times V^3} \times 427 \cdot 1.$

(3) The length constant $M = \frac{L}{\triangle^{\frac{1}{3}}} \times \cdot 3057.$

(4) The linear dimension constant $= \frac{\text{Dimension}}{\triangle^{\frac{1}{3}}} \times \cdot 3057.$

(5) The length speed constant $L = \frac{V}{\sqrt{L}} \times 1 \cdot 0552.$ Also $= \frac{K}{\sqrt{M}}$

(6) The skin constant $S = \frac{S}{\triangle^{\frac{2}{3}}} \times \cdot 09346.$ (See Appendix C).

For ships of the same model at corresponding speeds C and K are independent of absolute size (apart from skin friction correction). The skin friction curve is shown on type B, No. 1 plate. Let F_m = skin friction term in C value for model, F_s for ship. Then $F_m - F_s = (O_m - O_s)\ S\ L^{-\cdot 175}$. Tables for O_m and O_s, and $L^{-\cdot 175}$ can be found in Fyfe's book.

Mr. Froude's experiments were made on a vessel of the cruiser form, 350 ft. × 57 ft. × 22 ft. draught, from which he formed other five distinct types. The modifications in form were made by

snubbing the last 6 per cent. of the length of the fore end, and the same per cent. at the after end. The following Table gives the dimensions and other particulars :—

Table 1—Series A.

Mid-Area Coefficient for all Models ·8775.

Type	Length B.P.	Breadth	Draught	Length on L.W.L.	Displacement.	Block B.P.	Block on L.W.L.	Prismatics.				Snubbing from Type 1.
								F.B.	A.B.	Total	On L W L	
1	ft. 350	ft. 57	ft. 22	ft. 363·5	6100	·486	·4685	·538	570	·554	·534	
2	340	,,	,,	355·0	6083	·500	·4785	,,	601	·564	·545	A.B. 10 feet.
3	330	,,	,,	345·75	6056	·514	·4890	,,	634	·586	·556	A.B. 20 ,,
4	325	,,	,,	340·75	6048	·521	·4960	·553	,,	·593	·565	A.B. 20 ,, F.B. 5 ,,
5	320	,,	,,	335·75	6037	·528	·5020	·567	,,	·600	·572	A.B. 20 ,, F.B. 10 ,,
6	310	,,	,,	325·75	6008	·541	·5150	·598	,,	·616	·587	A.B. 20 ,, F.B. 20 ,,

Similar variations were made on another set of proportions of the same type of lines, the only difference being that the ratio of beam to draught was altered to 66 : 19. This he called series B. The body plan (Plate 4) and fore and after end sections (Plate 5) will serve to explain the above Table. By simply altering the scale of the cross-sectional area curve, keeping ratio of draught to beam unaltered, other models were made for each type.

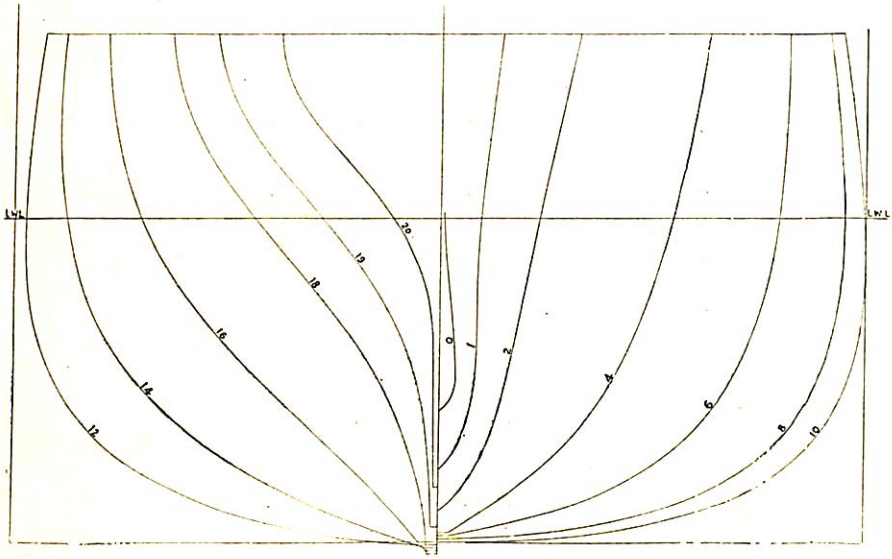


PLATE 4.
FROUDE BODY PLAN.

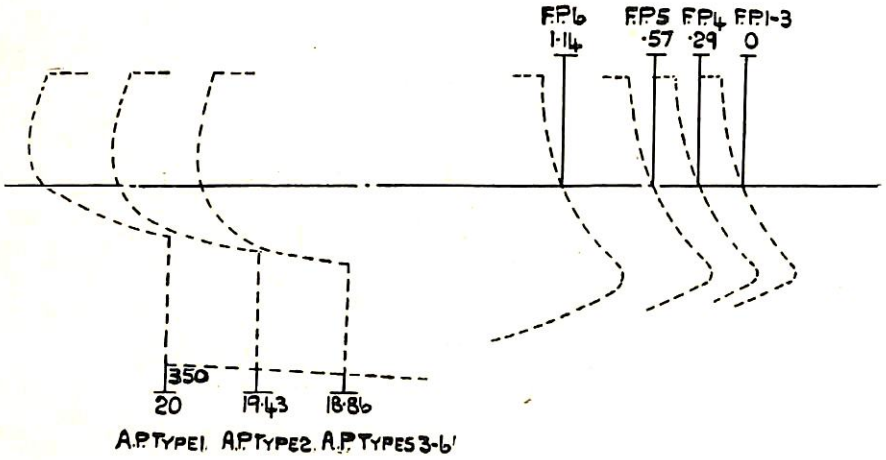


PLATE 5.

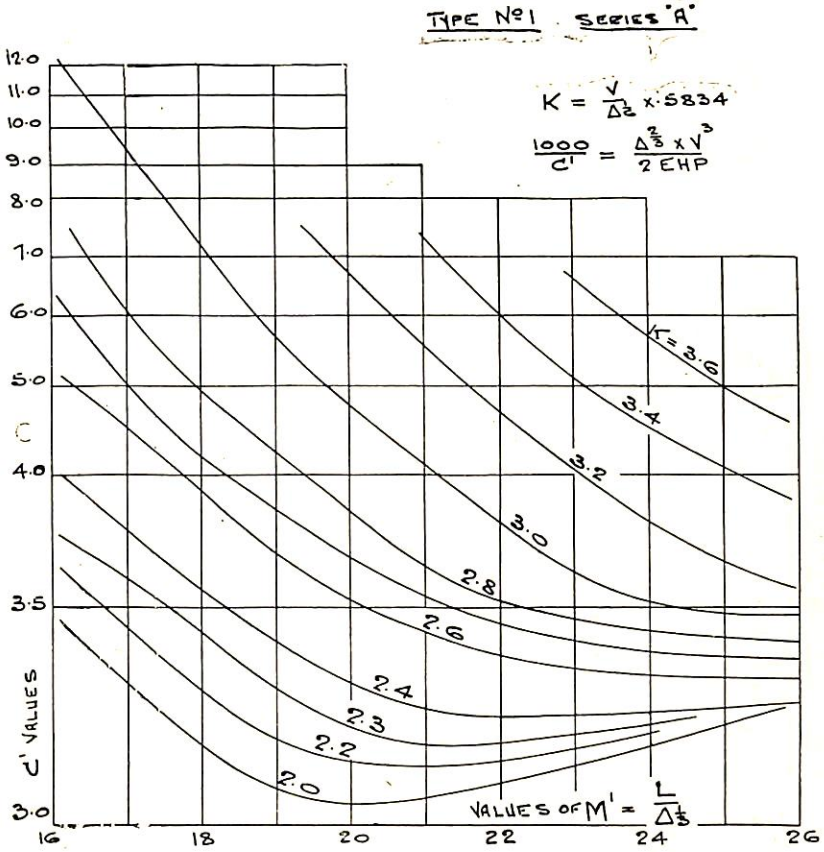

TYPE No 1 SERIES "A"
K = V/Δ^2 x·5834
1000/C' = Δ^⅔ x V^3 / 2 EHP
12·0
11·0
10·0
9·0
8·0
7·0
6·0
5·0
4·0
3·5
3·0
C' VALUES
16
18
20
22
24
26
VALUES OF M' = L/Δ^⅓
VT = 3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.3
2.2
2.0

PLATE 6. A1.

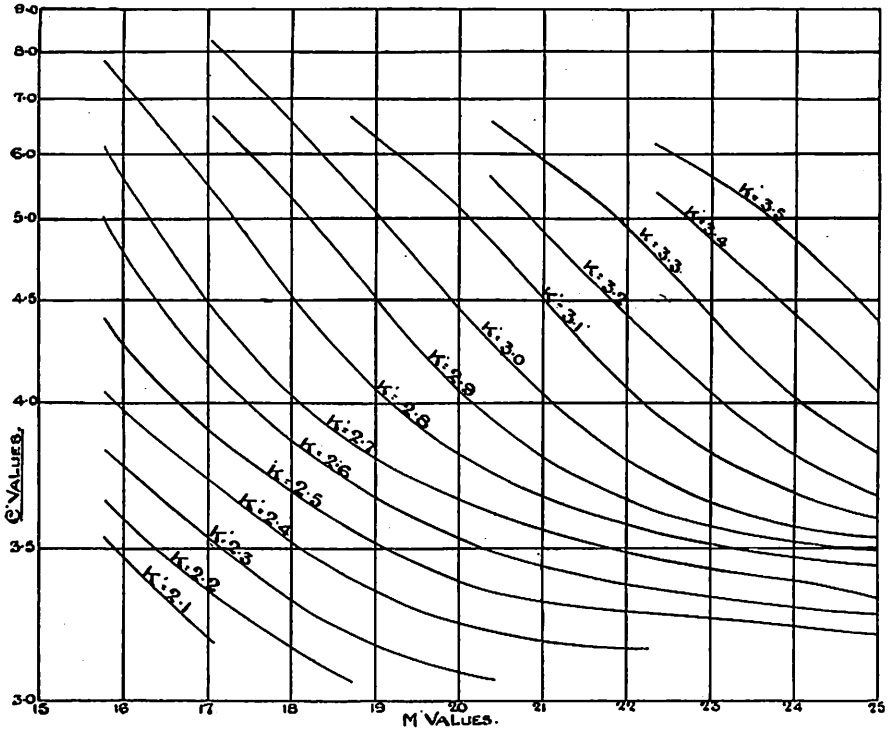


PLATE 7. A2.

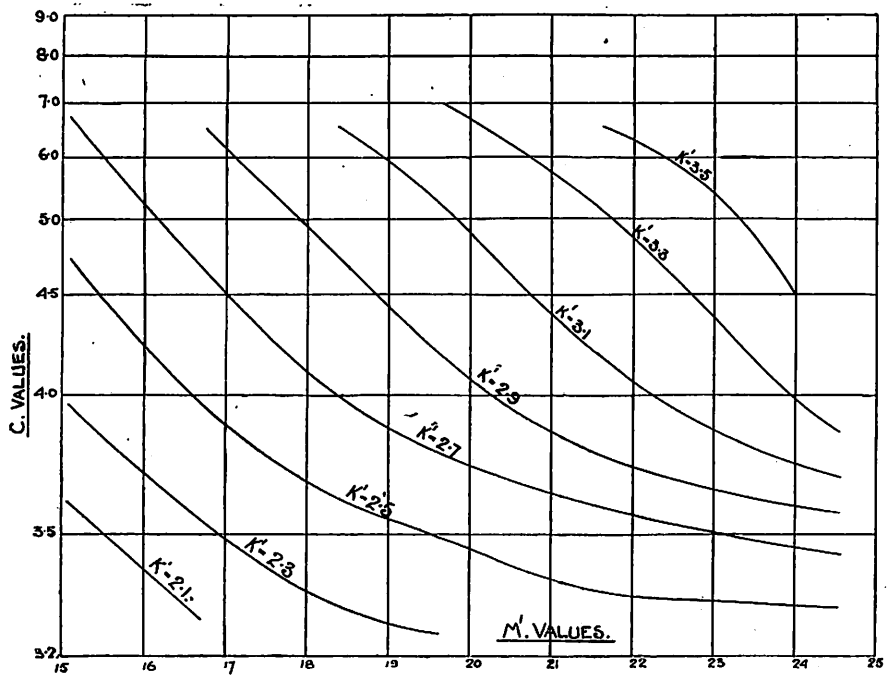


PLATE 8. A3.

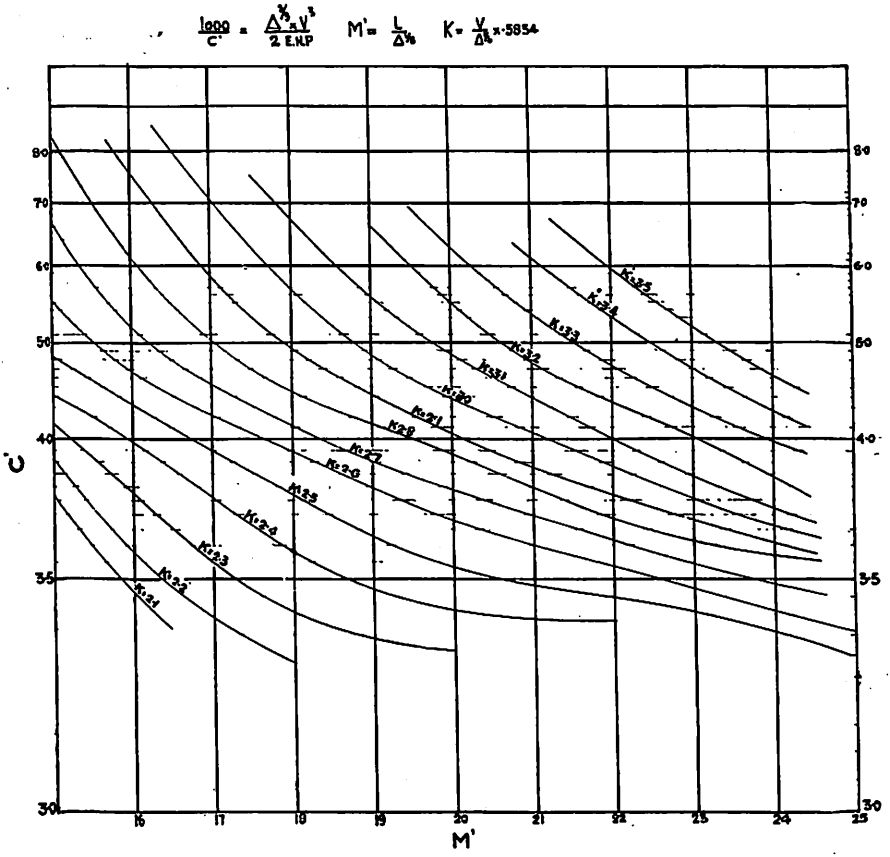

1000/C' = Δ^⅔ V^3 / 2 E.N.P
M' = L/Δ^⅓
K = V/Δ^⅙ x·5854
80
70
60
50
40
35
30
C
16
17
18
19
20
21
22
23
24
25
M'
K=3·5
K=3·4
K=3·3
K=3·2
K=3·1
K=3·0
K=2·9
K=2·8
K=2·7
K=2·6
K=2·5
K=2·4
K=2·3
K=2·2
K=2·1

PLATE 9. A4.

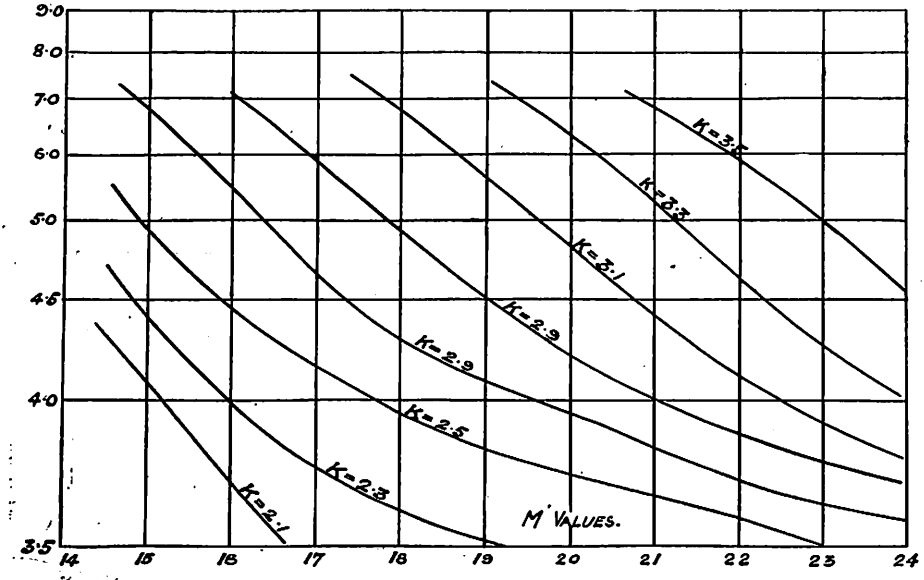


PLATE 10. A5.

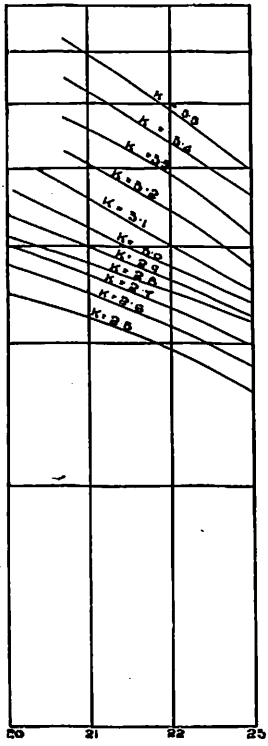


PLATE 11. A6.

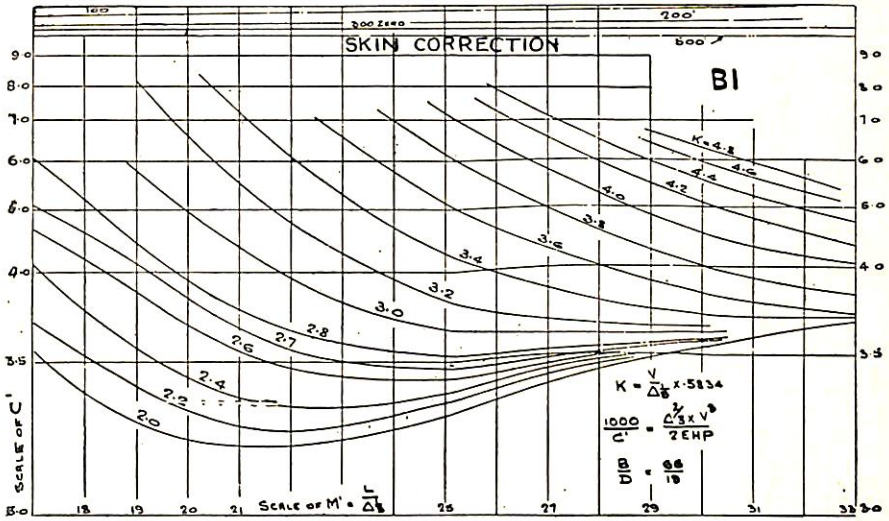


PLATE 12

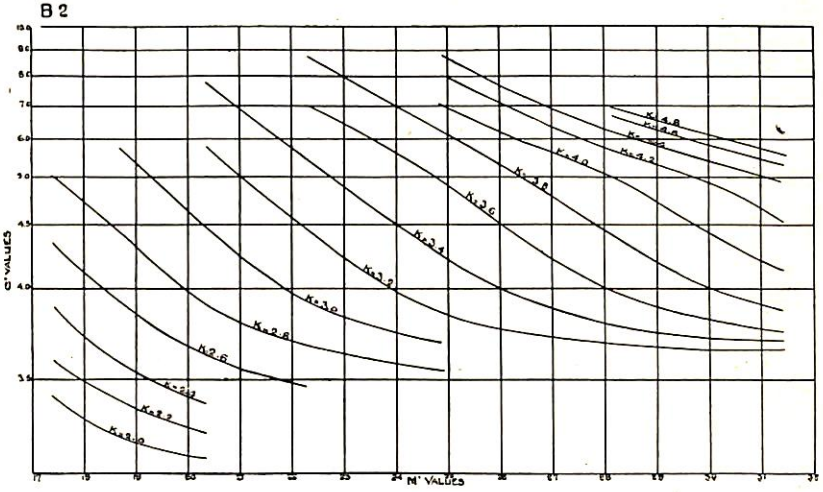


PLATE 13.

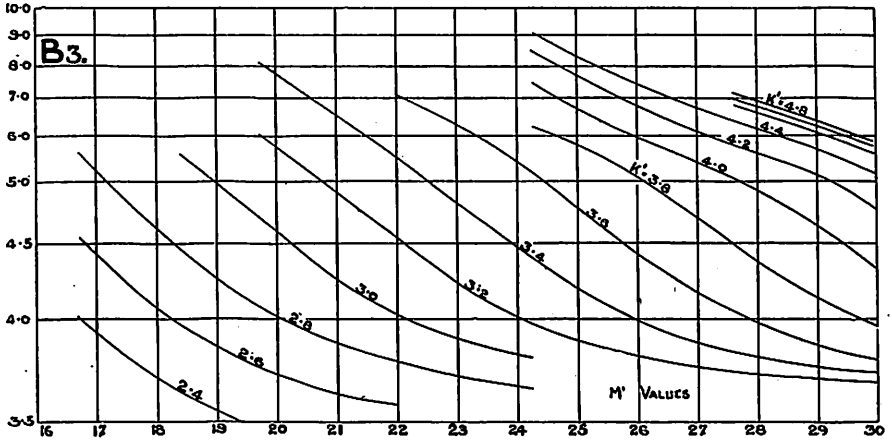
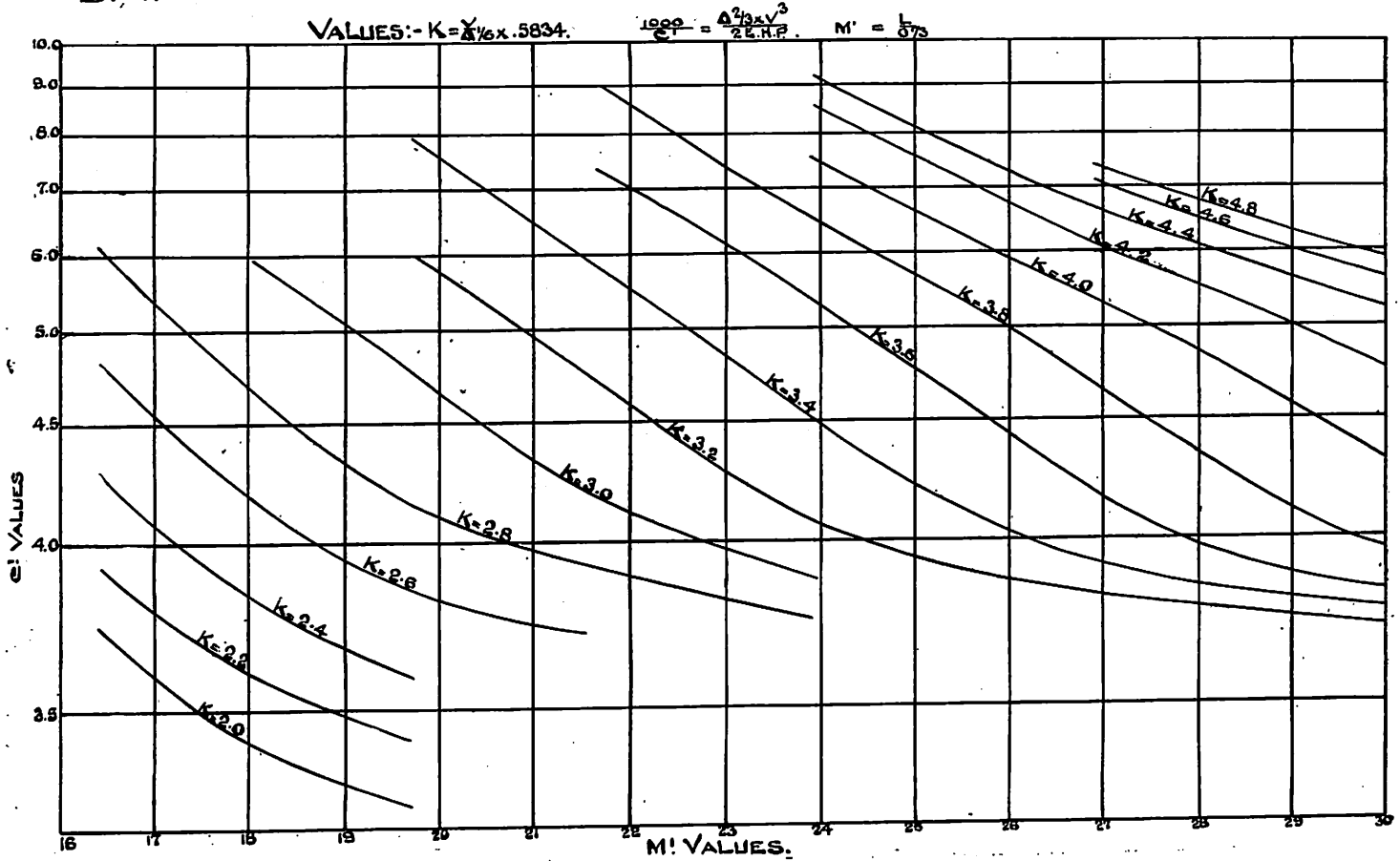


PLATE 14.

Mr. Froude recorded the results of all his experiments as follows, viz. :—C values are recorded in terms of M for constant values of K. These are called Iso. K curves. These results are embodied in the series of diagrams which will be found on the Plates 6-11 (A series) and 12-17 (B series) inclusive in a form which is much more handy for use than Mr. Froude's method. It will also be noticed that the constants have been modified. These curves are worth careful study. They especially illustrate the effect of length on propulsion. The scale for (C) is logarithmic, this scale having the effect of giving curves a much evener contour.

B. 4.


VALUES:- K = V/16 x .5834.
1000/C' = Δ^2/3 x V^3 / 2 H.P.
M' = L/Δ^1/3
10.0
9.0
8.0
7.0
6.0
5.0
4.5
4.0
3.5
C' VALUES
K=2.0
K=2.2
K=2.4
K=2.6
K=2.8
K=3.0
K=3.2
K=3.4
K=3.6
K=3.8
K=4.0
K=4.2
K=4.4
K=4.6
K=4.8
16
17
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30
M' VALUES.

PLATE 15.

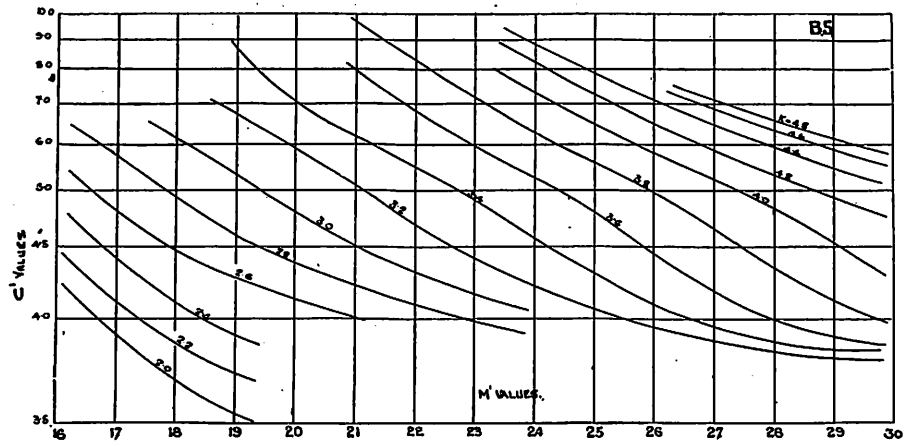


PLATE 16.

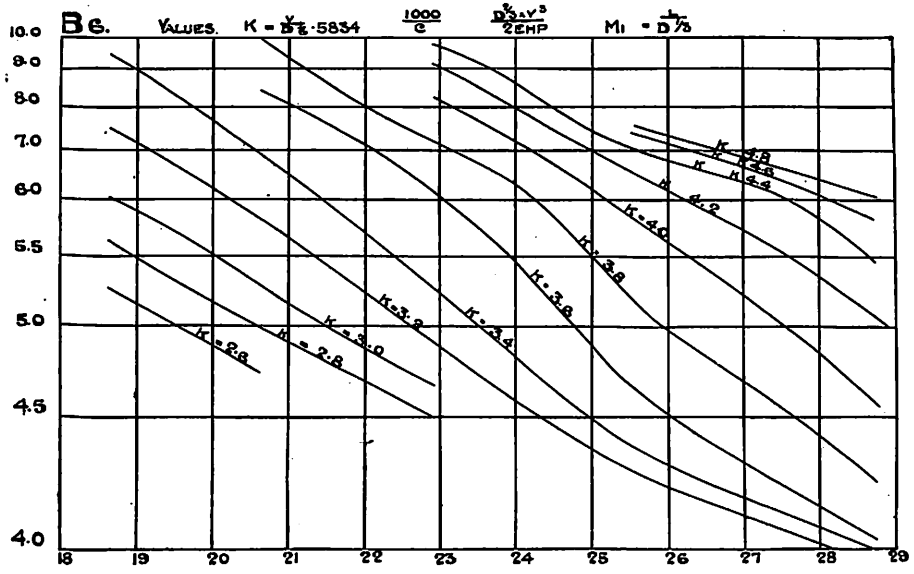


PLATE 17.

These results may be applied to design. Appended is a Table, giving the sectional areas as proportions of the midship area for the six types, and the load water-lines as proportions of the half-breadths, and these areas and water-lines in the form of curves. (See Plate 18).

Table 2.

Table of Sectional Areas and Load Water Lines for Froude's Models.

Sections.	Type 1.		Type 2.		Type 3.		Type 4.		Type 5.		Type 6.	
	Sectional areas.	Load water line.	Sectional areas.	Load water line.	Sectional areas.	Load water line.	Sectional areas.	Load water line.	Sectional areas.	Load water line.	Sectional areas.	Load water line.
20	...	...	...	...	...	...	...	...	...	...	...	...
19	·43	1·59	·57	2·11	·89	2·57	·88	2·53	·86	2·49	·82	2·43
18	1·27	3·32	1·64	3·89	2·08	4·47	2·04	4·42	2·02	4·37	1·92	4·25
17	2·46	4·93	2·91	5·44	3·47	6·02	3·42	5·95	3·34	5·88	3·23	5·76
16	3·80	6·34	4·30	6·78	4·87	7·23	4·78	7·16	4·69	7·09	4·54	6·96
15	5·23	7·50	5·68	7·82	6·24	8·18	6·15	8·11	6·05	8·04	5·85	7·92
14	6·64	8·40	7·05	8·63	7·51	8·88	7·42	8·82	7·30	8·76	7·09	8·65
13	7·94	9·08	8·27	9·25	8·63	9·42	8·51	9·36	8·42	9·32	8·19	9·20
12	8·98	9·57	9·22	9·67	9·48	9·77	9·36	9·74	9·28	9·70	9·10	9·61
11	9·69	9·89	9·82	9·93	9·90	9·96	9·86	9·95	9·80	9·93	9·69	9·88
10	9·98	9·98	9·99	9·99	10·00	9·98	10·00	9·99	9·98	10·0	9·97	9·98
9	9·86	9·92	9/80	9·88	9·70	9·83	9·78	9·90	9·82	9·90	9·92	9·94
8	9·35	9·65	9·21	9·56	9·15	9·46	9·20	9·55	9·30	9·62	9·54	9·76
7	8·42	9·06	8·27	8·95	8·08	8·82	8·26	8·96	8·44	9·08	8·83	9·34
6	7·19	8·18	7·03	8·05	6·84	7·90	7·10	8·10	7·33	8·30	7·85	8·66
5	5·78	7·04	5·61	6·90	5·46	6·77	5·76	7·02	6·04	7·26	6·65	7·76
4	4·28	5·65	4·15	5·52	4·03	5·41	4·34	5·72	4·46	6·02	5·32	6·63
3	2·87	4·05	2·80	3·96	2·69	3·84	3·01	4·21	3·28	4·60	3·96	5·35
2	1·64	2·42	1·60	2·36	1·54	2·28	1·80	2·68	2·09	3·09	2·69	3·86
1	·71	·98	·69	·95	·66	·92	·81	1·23	·96	1·58	1·45	2·15
0	·11	·07	·11	·07	·11	·07	·11	·07	·11	·07	·11	·07

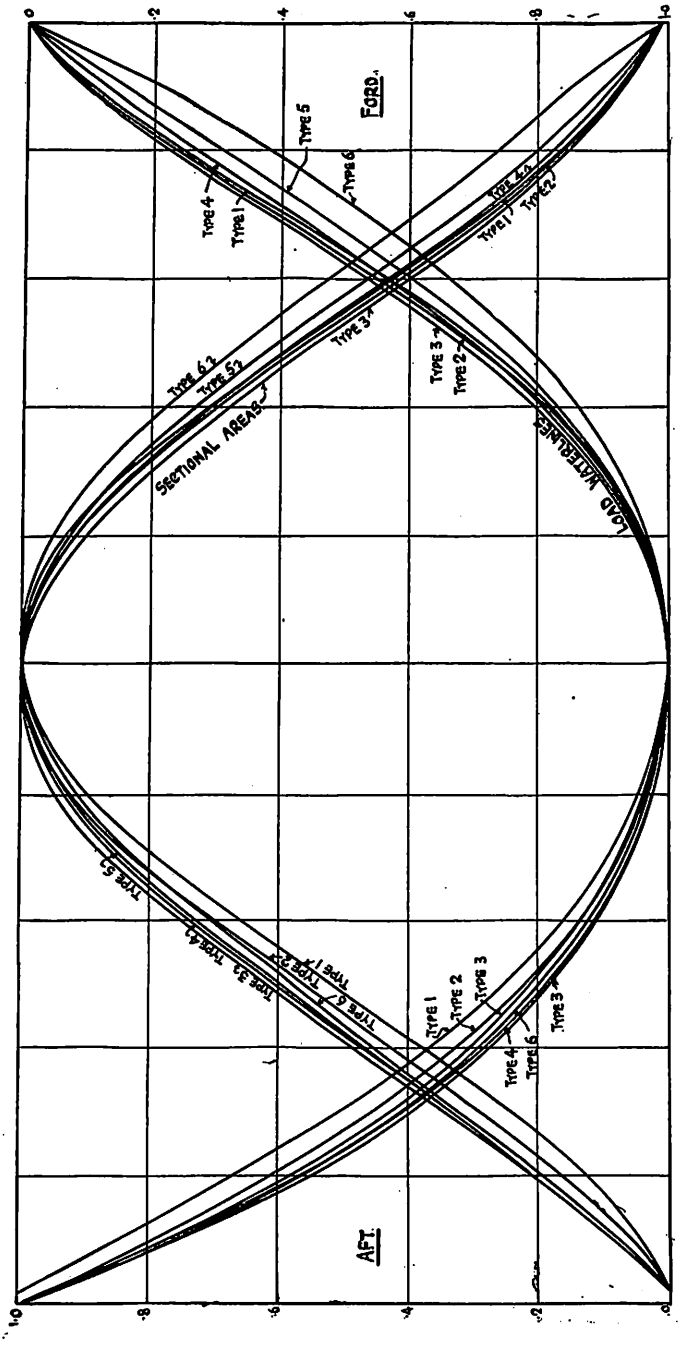

FORD.
AFT.
SECTIONAL AREAS
LOAD WATERLINES
Type 1
Type 2
Type 3
Type 4
Type 5
Type 6
Type 4a
Type 5a
Type 6a
Type 6 2
Type 5 2
Type 4 2
Type 3 2
Type 2 2
Type 1 2

PLATE 18.

Generally stated, Mr. Froude's conclusions are that the resistance of a form is determined solely by the curve of cross-sectional areas, together with the extreme beam and surface water-line of the fore body, and if these three are unaltered considerable ship-shape variations in cross sections can be made without affecting the resistance. Series A applies to designs where the ratio of draught to beam is ·386 and mid-area coefficient ·8775, and series B to ratios of ·288. For ratios between these two, the variation of C may be taken as arithmetical.

From the foregoing statements it will be seen that these results can be made use of for

(1) Some other proportion of beam to draught.
(2) Some other form of section.

Thus, suppose it is necessary to use a section of the form C of, say, ·92 to ·95 coefficient, which is much more common nowadays than ·8775 (see Plate 19), the method No. 2, as explained in Part I., can be used to form new body plan.

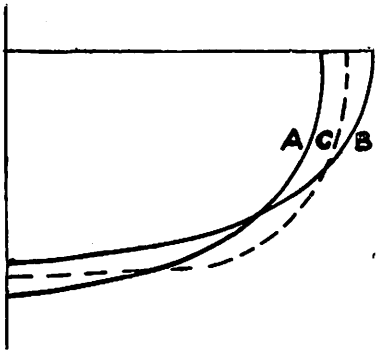


PLATE 19.

The body plan of Channel steamer, shewn on Plate 20, has been designed in accordance with type 5 in the fore body, as Mr. Froude has stated that the after body may be varied within limits without much effect on resistance. By varying the after body, thus any desired position of CB may be obtained. The designed draught is 11 ft. 8 in. mld., her breadth being 42 ft. 6 in. The corresponding Froude draught for type 5 B would be 12 ft. $2\frac{3}{4}$ in., with mid-area coefficient of ·8775, giving an area of 457 square feet, which on 11 ft. 8 in., if it were desired to have same displacement and sectional area-curve as type, would give a coefficient of ·919. In this particular design only, the sectional area curve and water-line were adhered to, the mid-area being 445 square feet, which gives a coefficient of ·897. Plate 21 shows the sectional area curve and load water-line. Other particulars are as follows :—

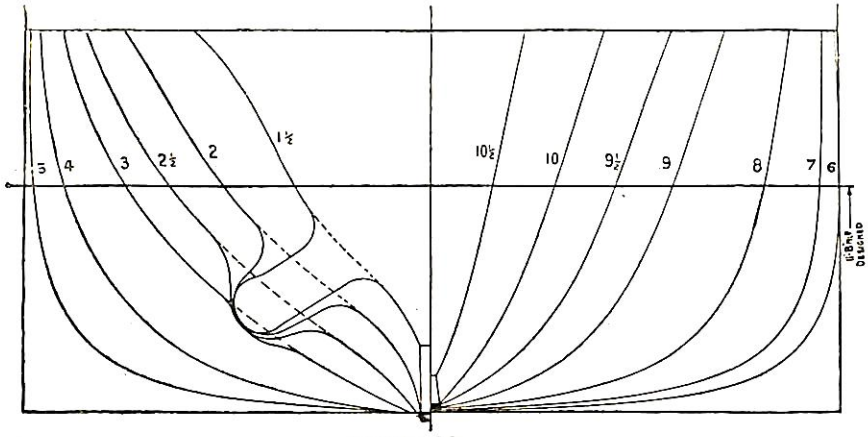


PLATE 20.

Displacement, 2700 tons.
Block mld. ex-bossing ·524, ex with bossing ·542.
Prismatic forward ·566, aft ·604 ; total ·585. CB aft 6·0 ft.
Speed, 22½ knots ; I.H.P. 10,000.

To illustrate the use of these curves, the I.H.P. has been worked out for the above design.

Suppose ship to be 350 ft. × 42 ft. 6 in. × 12 ft. 3 in. draught, 2750 tons displacement, and 22½ knots speed. The ratio of

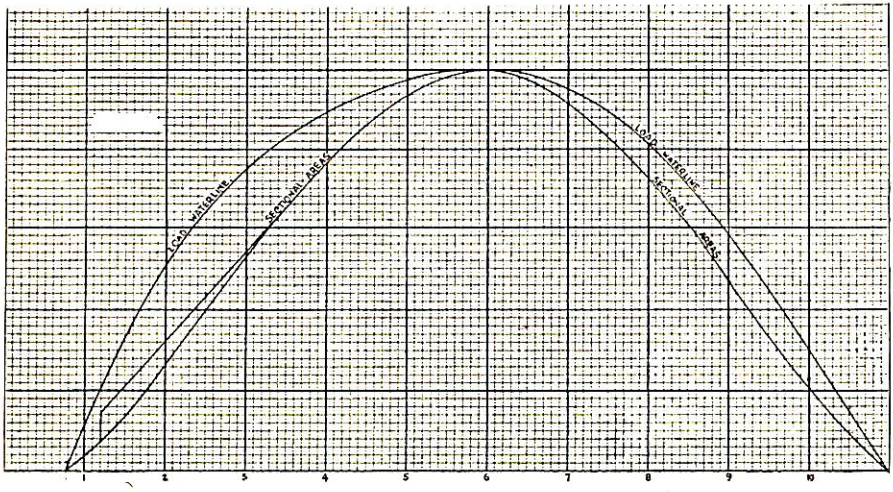


PLATE 21.

draught to beam is ·288 and block ·528. Hence vessel is of type 5, series B.

$$M^1 \text{ value is } \frac{L}{\triangle^{\frac{1}{3}}} = 24{\cdot}98$$

$$K^1 \text{ value } \frac{22{\cdot}5}{2750^{\frac{1}{3}}} \times {\cdot}5834 = 3{\cdot}5$$

At the M^1 value of 24·98 the C^1 value for K^1 value of 3·5 series 5 B is 4·52 for vessel of length 350 ft., a skin correction in this C^1 value has to be made, which will be found from diagram for No. 1 series to be ·01, and this will be a diminution, making $C^1 = 4{\cdot}51$.

$$\text{From the formula } \frac{1000}{C^1} = \frac{\triangle^{\frac{2}{3}} V^3}{2 \text{ E.H.P.}} \text{ we get}$$

$$\text{E.H.P.} = \frac{(2750)^{\frac{2}{3}} \times (22{\cdot}5)^3}{2000} \times 4{\cdot}51$$

$$= 5042.$$

Or taking propulsive coefficient of ·50, since an allowance will be necessary for appendages such as bossing, bilge keels, etc., we get I.H.P. = 10,084.

This vessel would have an immersed piece aft of the 350 feet as in the cruiser type of the curves.

The diagram, Plate No. 22,* will enable the best type of form for any K and M to be chosen. Each curve in the diagram is for a particular K value, and gives minimum C value obtained at that K value with any type of model, the best values being indicated by the numbers against the curves. K and M are usually fixed early in the design, and these curves, therefore, enable the best type to be chosen for the design. They are drawn for the A series only, as Mr. Froude found that the effect of form of area curve and water-line upon the general result was largely independent of the ratio of beam to draught.

Summing up in a few words the general conclusions to be deduced from Mr. Froude's experiments, a study of Plate 18 will at once show that the increase of prismatic obtained by snubbing is accompanied by a change in the shape of the area curve, the hollowness of the ends becoming less marked with increase of snubbing until it disappears at P = ·6. This change in the shape of the area curve produces an increase of the resistance at all moderate speeds, as a study of Plate 22 and Plates 6-17 will show. However, if the vessel is forced to very high speeds for its length, then this area curve produced by snubbing gives decidedly better results,

* Baker's Book on Resistance.

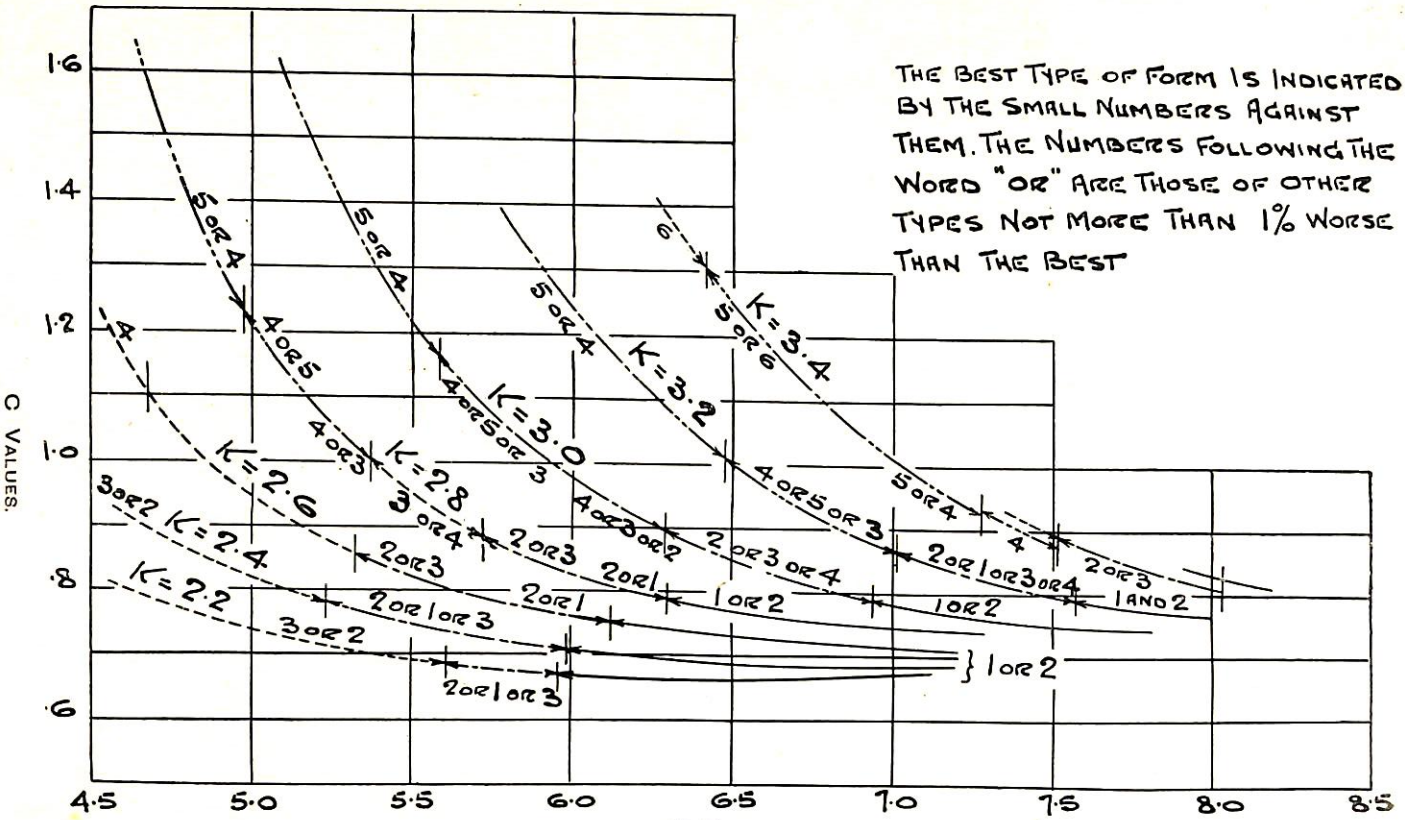

THE BEST TYPE OF FORM IS INDICATED BY THE SMALL NUMBERS AGAINST THEM. THE NUMBERS FOLLOWING THE WORD "OR" ARE THOSE OF OTHER TYPES NOT MORE THAN 1% WORSE THAN THE BEST
C VALUES.
M VALUES.
1·6
1·4
1·2
1·0
·8
·6
4·5
5·0
5·5
6·0
6·5
7·0
7·5
8·0
8·5
K = 3·4
K = 3·2
K = 3·0
K = 2·8
K = 2·6
K = 2·4
K = 2·2
6
5 OR 4
4 OR 5
4 OR 3
4 OR 5 OR 3
3 OR 4
3 OR 2
4 OR 3 OR 2
2 OR 3
2 OR 1
2 OR 3 OR 4
1 OR 2
2 OR 1 OR 3
2 OR 1 OR 3 OR 4
1 AND 2

PLATE 22.

as in the cruiser type of curve in Plate 42, where speed length ratio is about 1·4. The penalty for stern snubbing is never very great.

Generally stated, the conclusions of Baker, Taylor and Froude for curves of areas with no parallel body are as follows :—For values of $\frac{V}{\sqrt{L}}$ ·7 to 1·2 prismatic about ·6 the forward half of the curve of areas should be decidedly convex to base tending to become tangential. The bow water-lines should be kept as fine as possible consistent with stability, and with slight hollow in it. The after-body area curve should be much the same as fore-body, but should be combined with fairly full water-line to prevent squatting at high speeds. However, if kept too full it may result in blunt ends, and, consequently, eddy-making. A cruiser stern, or one of the type of Channel steamer, shewn in Plate 20, partly avoids this. For higher values of $\frac{V}{\sqrt{L}}$ the fore end of the curve of fore body may be straightened as in cruiser type (see Plate 42) with advantage, as the $\frac{V}{\sqrt{L}}$ increases, until it may be even concave to the base line as in the torpedo boat type (see Plate 42), where $\frac{V}{\sqrt{L}} = 1{\cdot}95$. For Channel steamers running about $V = 1{\cdot}2\sqrt{L}$ straight bow lines best, and maximum ordinate of water-line should be aft amidships. Displacement should be small, or, in other words, the smaller the $\frac{\triangle^{\frac{1}{3}}}{L}$ ratio the better the result.

Taylor gives the following Table as the best relation between $\frac{V}{\sqrt{L}}$ and prismatic for minimum residuary resistance :—

$\frac{V}{\sqrt{L}}$,	1·1	1·25	1·50 and above.
Best prismatic about	·57	·60	·65

Broad ships require rather higher and narrow ships rather lower coefficients than those given.

For ships over ·6 prismatic, it becomes necessary to introduce parallel body, or curve will become convex. This type of curve, however, may be used with advantage in the after-body of destroyers, steam yachts, or shallow draught vessels (see Plate 42). From the practical point of view, in the ordinary ship the intro-

duction of parallel body is a saving in labour and expense, besides benefitting propulsion.

From the above it will be seen that a curve of areas which may suit one set of speed conditions will not be suitable for another. Therefore, if a design has been found successful, it is well to adhere to its sectional area curve, especially in the fore body. Any increase in displacement can be added at the buttocks of the after-body, of course keeping the curve fair.

Cargo Ship Type (Area Curve and Proportions).

Introductory.

In recent years a vast amount of experimental work has been published in connection with the best form and proportions for cargo vessels.

In Great Britain, Messrs. Baker and Kent, of the National tank, and Semple of the Clydebank tank, have been notable contributors to this field of knowledge. In America, M'Entee and Sadler, and in Germany, Schaffran have published some valuable papers, especially M'Entee. Their findings apply more particularly to the ordinary cargo vessel of fairly full form, ranging from ·7 to ·8 block and as the major portion of our tonnage lies between these limits it will at once be seen how valuable these results are.

These remarks apply more particularly to Baker and M'Entee's findings, as Sadler has covered a wider field and much information on the fast and intermediate liner type can be gleaned from his experiments.

Before the curve of areas can be properly fashioned, it is necessary to discuss the various elements and proportions that enter into a design. At this point, before entering into a detailed discussion of these elements, it will be useful to state the various forms of resistances which a cargo vessel experiences and their relative magnitude.

At quite low speeds, the largest proportion of the resistance is that due to skin friction, but there is also some due to wave-making and eddy formation. The skin friction amounts to about 80 per cent. of the total. As the speed increases, the proportion due to wave-making increases, and at the limiting practical speed, it will amount to from 25 to 30 per cent. of the total.

In tramp steamers it is impossible to eliminate a certain amount of eddy-making at the stern, in the way of the post. The waves created consist of divergent sets at each end and transverse waves.

Economy in wave-making can be effected by so arranging the shape that the bow transverse waves tend to cancel the stern waves at such speeds as these may be important. This matter will be explained in greater detail when dealing with the elements entering into wave formation.

TABLE 12.

TABLE SHOWING PERCENTAGE OF PARALLEL MIDDLE BODY, AT WHICH THE RESISTANCE IS MINIMUM FOR ANY GIVEN SPEED, AND THE VALUE OF THE E.H.P. AT THAT SPEED.

Value of $\frac{\text{E.H.P.}}{\text{Displ.}} \div \left(\frac{V}{\sqrt{L}}\right)^3$ and per cent. of Parallel Middle Body.

$\frac{B}{d}$ Ratio	Speed Length Ratio.	Varying Bows. Medium Stern.			Varying Sterns. Medium Bow.			Varying Bows. Medium Stern.			Varying Sterns. Medium Bow.			Speed Length Ratio.	$\frac{B}{d}$ Ratio
		U	M	V	U	M	V	U	M	V	U	M	V		
3·73	·30	·845	·825	·860	·885	·925	·849	·665	·630	·656	·656	·690	·648	·30	2·26
		31·0%	25·2%	22·0%	27·0%	31·5%	19·7%	19·5%	28·0%	26·0%	32·0%	28·5%	21·0%		
	·40	·852	·850	·852	·890	·850	·885	·640	·595	·626	·610	·618	·590	·40	
		27·5%	28·5%	31·5%	26·0%	32·0%	27·5%	25·0%	25·5%	26·0%	28·0%	36·0%	22·5%		
	·45	·870	·875	·845	·890	·890	·880	·635	·605	·605	·625	·625	·590	·45	
		26·0%	30·5%	32·0%	32·0%	32·0%	31·0%	28·5%	25·5%	26·0%	29·5%	34·5%	23·0%		
	·50	·880	·885	·850	·890	·885	·915	·636	·605	·598	·610	·605	·590	·50	
		25·8%	34·0%	32·0%	32·5%	32·0%	36·0%	30·5%	27·5%	28·0%	31·0%	32·0%	23·0%		
	·55	·885	·890	·865	·885	·910	·920	·635	·615	·585	·605	·615	·590	·55	
		26·0%	36·0%	32·0%	29·0%	32·0%	41·0%	36·5%	30·0%	30·5%	32·0%	29·0%	22·5%		
	·60	·885	·903	·870	·905	·915	·920	·636	·620	·588	·605	·605	·595	·60	
		25·8%	35·5%	32·0%	22·0%	32·0%	37·0%	32·5%	31·5%	32·0%	32·0%	28·0%	28·2%		
	·65	·895	·940	·880	·905	·930	·930	·640	·620	·605	·615	·615	·615	·65	
		26·0%	33·0%	29·5%	20·0%	32·0%	33·5%	32·0%	31·5%	32·0%	32·0%	29·5%	22·0%		
	·70	·907	·945	·996	·975	·990	·957	·668	·652	·650	·670	·630	·665	·70	
		24·0%	26·5%	18·5%	21·5%	32·0%	33·0%	29·0%	30·0%	30·0%	32·0%	30·5%	21·0%		
	·75	·895	·935	·880	1·04	1·06	1·03	·695	·710	·710	·780	·800	·750	·75	
		20·7%	20·0%	11·0%	26·0%	32·0%	33·0%	21·0%	25·5%	26·0%	32·0%	30·0%	20·5%		
2·80	·30	·720	·705	·720	·720	·770	·725	·630	·620	·650	·648	·650	·628	·30	2·02
		31·0%	24·0%	12·0%	30·5%	30·5%	24·0%	18·0%	21·0%	23·5%	24·5%	25·0%	23·0%		
	·40	·710	·710	·705	·705	·740	·690	·600	·572	·600	·605	·590	·585	·40	
		27·0%	28·0%	32·0%	30·5%	33·0%	21·0	22·5%	25·5%	24·5%	24·0%	31·5%	22·5%		
	·45	·725	·710	·695	·710	·705	·690	·590	·555	·595	·595	·585	·580	·45	
		27·5%	30·5%	33·5%	30·5%	33·0%	21·0%	25·0%	26·0%	31·0%	25·5%	32·0%	22·0%		
	·50	·740	·710	·695	·705	·710	·702	·590	·505	·545	·585	·572	·520	·50	
		30·0%	32·0%	34·0%	30·5%	31·5%	21·0%	25·5%	26·5%	26·0%	28·0%	32·0%	21·5%		
	·55	·740	·725	·705	·715	·720	·705	·605	·565	·545	·575	·570	·565	·55	
		31·0%	33·0%	34·5%	30·5%	29·5%	21·0%	26·5%	28·5%	31·5%	29·0%	32·0%	21·0%		
	·60	·742	·750	·720	·730	·735	·702	·610	·505	·550	·565	·558	·545	·60	
		31·5%	34·5%	33·5%	30·5%	28·0%	21·0%	30·5%	31·5%	28·5%	29·0%	32·0%	20·5%		
	·65	·740	·765	·730	·745	·750	·730	·610	·560	·560	·570	·570	·570	·65	
		29·5%	32·5%	32·0%	30·0%	28·5%	28·5%	29·5%	30·5%	29·5%	29·0%	32·0%	20·5%		
	·70	·745	·785	·765	·790	·810	·800	·620	·595	·600	·630	·630	·630	·70	
		26·0%	27·5%	26·0%	27·0%	30·0%	22·5%	26·0%	27·5%	27·0%	29·0%	32·0%	20·0%		
	·75	·765	·805	—	·895	·920	·900	·650	·660	·675	·745	·745	·730	·75	
		21·5%	20·0%	17·5%	22·5%	32·0%	31·0%	22·5%	24·0%	23·0%	29·0%	32·0%	19·5%		

Ship Dimensions.

Two of the principal ship dimensions, viz., length and draught, are so dependent on harbour facilities that in many cases this, and not propulsion at all, limit the designer in fixing them, and the problem is really that of producing the least resistful form of given displacement with these two dimensions fixed.

Stability considerations will probably fix the beam and deadweight considerations the fullness. Recently this question of limiting fullness has received great attention. In full ships of from ·78 to ·82 block, the speed has been found to be much more adversely affected by weather conditions than those of finer coefficients.

As a result of a series of investigations on several vessels of different blocks, ranging from ·806 to ·765, Mr. Hamilton of Liverpool came to the conclusion, from considerations of sea speed alone, that it is undesirable to go beyond ·77 to ·78 block for any ocean-going cargo vessel.

Mr. Kent has amply confirmed this statement during a series of voyages he made on several types of vessels and by a series of experiments just published, 1927. However, higher deadweight on given dimensions may influence many builders and owners to go in for fuller ships.

Except at very low speeds, the resistance per ton of a ship having large beam and draft is much greater than that of a ship having smaller lateral dimensions with the same length, speed and fineness. The length displacement ratio (Froude's $\frac{L}{W^{\frac{1}{3}}}$ Taylor's $\frac{W}{(\cdot 01\ L)^3}$) is thus one of the most important factors affecting resistance at high speeds. In fast ships, attention must also be given to the relation between length and speed, as well as to that between length and displacement, remembering that additional length involves increased frictional resistance, so that one must balance this with the decrease in residuary resistance.

The following Table gives the average values for these ratios:—

Table 3.

Class of Ship.	$\frac{L}{W^{\frac{1}{3}}}$	$\frac{V}{\sqrt{L}}$
Very Full Cargo Ships, ...	16·5 to 17·5	·5 to ·55
Average Full Cargo Ships,	17·5 ,, 18·5	·55 ,, ·62
Fine Cargo Ships, ...	18·5 ,, 19·5	·62 ,, ·70
Intermediate Liners, ...	19·5 ,, 21·0	·70 ,, ·85
Fast Passenger Liners, ...	21·0 ,, 23·0	·85 ,, 1·0

Wetted Surface.

Wetted surface is very non-sensitive to such elements as proportion of parallel body in length and prismatic coefficient, but depends mainly on cross dimensions ; the smaller it is kept per ton of displacement consistent with non-wave making the better will be the propulsive performance. With fixed beam the wetted surface per ton will drop as the draught is increased and a similar drop is obtained if draught is fixed and beam increased. The best ratio of beam to draught is that which gives precisely the same reduction of skin per ton for either beam or draught reduction. Mr. Baker has found that for ships of about 30 per cent. parallel body, the best ratio of beam/draught is about 2·8 and somewhat less than this for forms of 50 per cent. parallel body.

Area and Shape of Midship Section.

The ratio found in the preceding heading should be taken into consideration when fixing shape of midship section.

Mr. Baker states that for a given speed and displacement there is a mid-area most suitable for low wave-making. The following formula gives this area, viz.,

$$A = \frac{6{\cdot}29 \ \triangle \ P^2}{V^2}$$

where V = speed in knots.
$\triangle$ = displacement in tons.

$$P = \text{wave-making constant} = {\cdot}746 \ \frac{V}{\sqrt{p \times L}}$$

where p = prismatic coefficient and L length between perpendiculars. P expresses the relation of the speed of the ship to the speed of a wave, having a length from crest to crest equal to $p \times L$. This matter will be discussed further under another heading.

The most appropriate limits to the value of P for low wave-making can be obtained from Plate No. 23, where the unshaded portions give minimum resistance. By putting the values of P obtained from this Plate in the above equation, limiting values of A can be found. This Plate, originally published by Mr. Kent, when used intelligently in this connection will be found of immense value. The portions shaded are to be avoided as they indicate the region of humps or where excessive resistance takes place.

Taylor, Baker's, etc., results all point to the largest possible area being given to this section, consistent with other design features, in vessels of this type. Coefficients of ·98 to ·99 are quite common nowadays, and these can be worked in where there is large amount of parallel body by giving no rise of floor and greater bilge radius than with rise of floor.

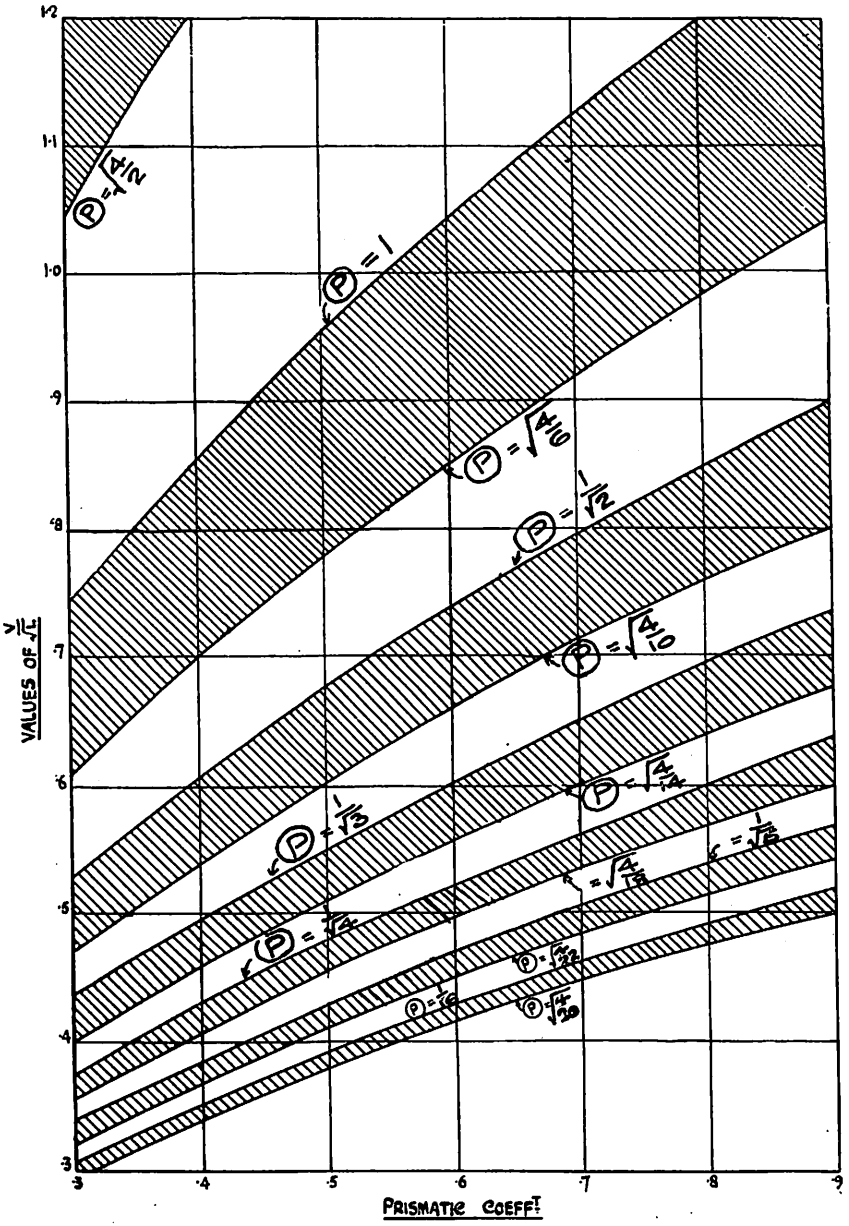

VALUES OF $\frac{V}{\sqrt{L}}$
PRISMATIC COEFF.
1·2
1·1
1·0
·9
·8
·7
·6
·5
·4
·3
·4
·5
·6
·7
·8
·9
$P = \sqrt{\frac{\Delta}{L^3/2}}$
$P = 1$
$P = \sqrt{\frac{\Delta}{L^3/10}}$
$P = \frac{1}{\sqrt{12}}$
$P = \sqrt{\frac{\Delta}{L^3/10}}$
$P = \frac{1}{\sqrt{13}}$
$P = \sqrt{\frac{\Delta}{L^3/14}}$
$P = \sqrt{\frac{\Delta}{L^3/15}}$
$P = \frac{1}{\sqrt{15}}$
$P = \sqrt{\frac{\Delta}{L^3/16}}$
$P = \frac{1}{\sqrt{16}}$
$P = \sqrt{\frac{\Delta}{L^3/20}}$

PLATE 23.

Having found this area and assuming draught to have been already fixed, beam is determined, and, provided stability considerations are satisfactory, the prismatic coefficient can now be obtained and wave-making characteristics determined.

The problem can be solved in another way and this usually is the method employed, by the tentative process of assuming mid-area, length and prismatic coefficient and finding from a study of Plate No. 23 whether this results in good or bad performance.

Longitudinal Distribution of Displacement.

The longitudinal position of the centre of buoyancy usually fixes this, but as this is adjustable within limits, especially in cargo vessels, usually a satisfactory distribution of displacement for minimum resistance can be obtained.

The main elements entering into this are amount and position relative to mid-section of parallel body, or expressed in another way, the ratio of entrance to run.

Considered from a resistance point of view, the L.C.B. would be well forward of mid-section in full vessels and aft in fine, high-speed ships. Considered from a disposition of weight point of view, cargo ships—especially single screws—demand a centre of buoyancy at load draught, the usual basis condition chosen, forward of the mid section, whilst passenger and war vessels demand it aft, thus in both cases not conflicting with the resistance point of view. As regards its position for definite types, in the ordinary cargo vessel carrying general cargo the desired trim may be obtained by a suitable distribution of cargo, but where the ship is carrying one type of cargo—as, for example, meat—there is not so much latitude, and in this case it is more essential to arrive at the exact position of the L.C.G. in the light condition, the locating of the centre of the cargo being a matter of geometry. In this type it is advisable in many cases to leave the fore-hold non-insulated for general cargo of greater density, especially if the ship carries general cargo on the outward voyage, and has been designed with a C.B. well forward for this condition.

Of course it must be understood that the draught carrying meat would probably be about 80 per cent. of the load draught, as obtained from the Freeboard Tables, therefore involving a C.B. further forward than at deep load, as the locus of L.C.B. is generally further forward at lower draughts. With the liner type and cross-channel steamer, and in fact all fast non-cargo carrying vessels, the location of the L.C.G. when light is very essential, the only means of rectifying trim in these cases being water ballast, an unremunerative method.

The following figures give a rough guidance to the position of the L.C.B. from amidships for different types in terms of length :—

Liners, ·010 L to ·014 L aft.
Channel Steamers Mail, ·008 L to ·020 L aft.
Cargo Vessels, single screw, ·005 L to ·01 L forward; ·008 L good average.
Cargo Vessels, twin screw, amidships to ·008 L aft.

Parallel Body—Economic Length of.

From a building and owners' point of view, as great an amount of parallel body as can be obtained is a great desideratum. To obtain the greatest length of parallel body, consistent with low residuary resistance, the papers delivered by Mr. Baker in 1913, 1914 and 1915, and by Mr. Kent in 1919 give probably the best index.

Mr. Taylor, in America, carried out a series of experiments on models of ·68, ·74 and ·80 prismatics, inserting five different lengths of parallel body in each, displacement and dimensions remaining constant.

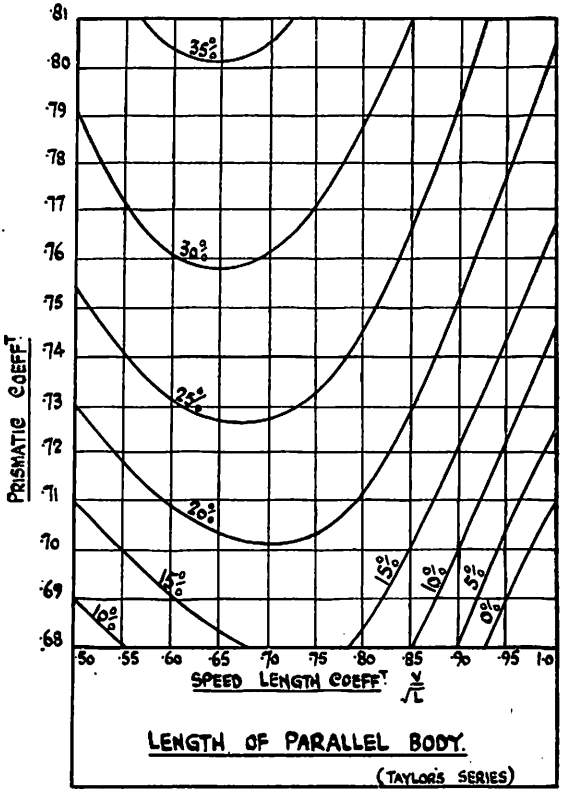


PLATE 24.

At high speeds the most resistful were invariably those with fine ends and most parallel body. At more moderate speeds there was a certain percentage of parallel body for each prismatic coefficient which gave the minimum residuary resistance, this length varying a little with the speed.

Plate No. 24 gives these results in the form of curves.

The percentages obtained from this Diagram may be varied up or down at low speeds without much effect on resistance. The increase in frictional resistance as more parallel body was added was negligible.

It may here be added that parallel body with full forms, although an advantage in the fore-body, should be used as little as possible in the after-body, as the shorter run increases the resistance due to eddy-making.

It should be here noted that in these experiments of Taylor, increased length of parallel middle body was naturally associated with an entrance and run of increasingly hollow lines not usually the case in practice. In Baker's experiments, however, the dimensions were kept constant and displacement varied, probably on the whole giving a better criterion for fixing this length.

Mr. Kent's paper of 1919 on the effect of beam on the resistance gave some useful information on determining the amount of parallel body. The following Table, taken from this paper, will serve to illustrate this point :—

Table 4.

Effect upon power of increasing the fullness by reduction of beam and increase of parallel body.

Length between perpendiculars, 400 feet.
Draught, ... 23·23 ,,

Set.	Prismatic Coefft.	Per-centage Parallel Body.	10,000 tons displacement.				12,000 tons displacement.				14,000 tons displacement.			
			Beam	© values at			Beam	© values at			Beam	© values at		
				10 knots	12 knots	14 knots		10 knots	12 knots	14 knots		10 knots	12 knots	14 knots
			feet.				feet.				feet.			
L	·655	0	58·8	·641	·654	·681	70·6	·670	·690	·740	82·9	·723	·752	·823
M	·689	10	55·9	·641	·660	·679	67·0	·670	·705	·741	78·3	·700	·751	·795
N	·758	30	50·7	·627	·672	·740	61·0	·650	·694	·748	71·0	·682	·725	·780
O	·827	50	46·5	·685	·713	·900	56·0	·731	·759	·952	65·2	·796	·858	1·063

It will be seen from a study of this Table that at 10 knots an increase in the fullness of the form by the addition of parallel body, accompanied by a decrease in beam sufficient to keep the displace-

ment the same, will give improved results up to about 30 per cent. of parallel body or prismatic of about ·76. Above this limit, resistance for any speed increases rapidly.

Table 5 shows the effect of introducing parallel body as beam and draught are reduced, keeping $\frac{\text{Beam}}{\sqrt{\text{Mid Area}}} = 1{\cdot}69$. For sets L, M, N, the © value remains fairly constant, but set O shows a marked increase as parallel body is introduced. This is probably due to eddy-making caused by the shorter run in this set. This is supported by the 1914 experiments on varying prismatic of stern, as will be seen later when dealing with this paper.

$\frac{\text{Length of Run}}{\sqrt{\text{Mid Section Area}}}$ should exceed 4·08, *i.e.* for all these models the length of run should be greater than $\frac{4{\cdot}08}{1{\cdot}694} \times$ beam or 2·41 beams.

Table 5.

Effect upon the power of increasing the fullness by a reduction of beam and draught and an increase in parallel body.

Length between perpendiculars, 400 feet.

Ratio $\frac{\text{Beam}}{\sqrt{\text{Mid Area}}} = 1{\cdot}694$.

Set.	Percentage Parallel Body.	Beam.	Draught	Prismatic Coefft.	© at 10 knots.	© at 12 knots.	© at 14 knots.
		feet.	feet.		10,000 tons displacement.		
L	0	62·2	22·18	·649	·660	·670	·695
M	10	60·7	21·65	·680	·660	·689	·706
N	30	58·2	20·75	·741	·661	·712	·764
O	50	55·65	19·65	·828	·730	·784	·952
					12,000 tons displacement.		
L	0	67·7	24·1	·657	·655	·674	·717
M	10	66·1	23·5	·688	·667	·701	·737
N	30	63·1	22·5	·755	·661	·708	·756
O	50	60·4	21·5	·825	·758	·822	1·010
					14,000 tons displacement.		
L	0	72·9	25·88	·661	·666	·681	·740
M	10	71·2	25·3	·691	·667	·708	·750
N	30	68·0	24·15	·770	·679	·710	·765
O	50	65·4	23·27	·821	·797	·862	1·064

The maximum beams above which, according to this rule, it is not possible to avoid eddy-making are given in Table 6.

Table 6.

Set.	Length of Run.	Maximum Beam to avoid eddymaking.
	feet.	feet.
L	200	83
M	180	75
N	162	67
O	116	48

Valuable information on the maximum amount of parallel body can be obtained in Prof. Sadler's 1921 paper on " The Influence of Shape of Transverse Sections upon Resistance," and M'Entee's 1919 paper on " The Effect of varying amount of Parallel Body and Prismatic Coefficient simultaneously." These papers are treated in a fuller manner under another heading.

Ratio of Length of Entrance to Run or position of Parallel Body relative to Midships.

Mr. Baker's 1913 paper contains very valuable data on this ratio and the following Tables, giving these results in tabular form, will enable the designer to fix this ratio and also approximate to his horse power.

There were five different sets tried of the following dimensions, etc., corrected for 400 ft. ship, as given in Table 7.

Mr. Baker's (C) values were plotted to a base of (K) values

where $(C) = \frac{E.H.P. \times 427{\cdot}1}{\triangle^{\frac{2}{3}} \times V^3}$ and $K = \frac{V}{\triangle^{\frac{1}{6}}} \times {\cdot}5834.$

Table 7.

Set.	Length.	Breadth	Draft	Parallel Body.	Ratios.		Prismatic Coefficients.		Mid Area Coeff.
					Beam / Draft	Length / Beam.	Entrance	Run.	
	feet.	feet.	feet.	per cent.					
A	400	50	22·22	10	2·25	8	·52	·584	·980
B	,,	52·6	23·21	10·44	,,	7·6	·57	,,	,,
C	,,	,,	,,	30	,,	,,	,,	,,	,,
D	,,	,,	,,	,,	,,	,,	·672	·638	,,
E	,,	,,	,,	50	,,	,,	,,	,,	,,

The following chart, Table 8, giving these results in terms of E.H.P. and speed in knots, will at a glance show the effect of this ratio of length of entrance to run on the resistance.

For high proportions of parallel body (50 per cent.) an $\frac{\text{entrance}}{\text{run}}$ of about ·9 is best and there is something to be gained by working the entrance shorter than the run even with 30 per cent. parallel body. As has been stated before, the prime cause of this advantage of a low ratio of $\frac{\text{entrance}}{\text{run}}$ is the avoidance of eddy-making at the stern by the longer run obtained, and provided this is attained the resistance is not very sensitive to this ratio, and this permits of a certain freedom in adjusting the longitudinal C.B.

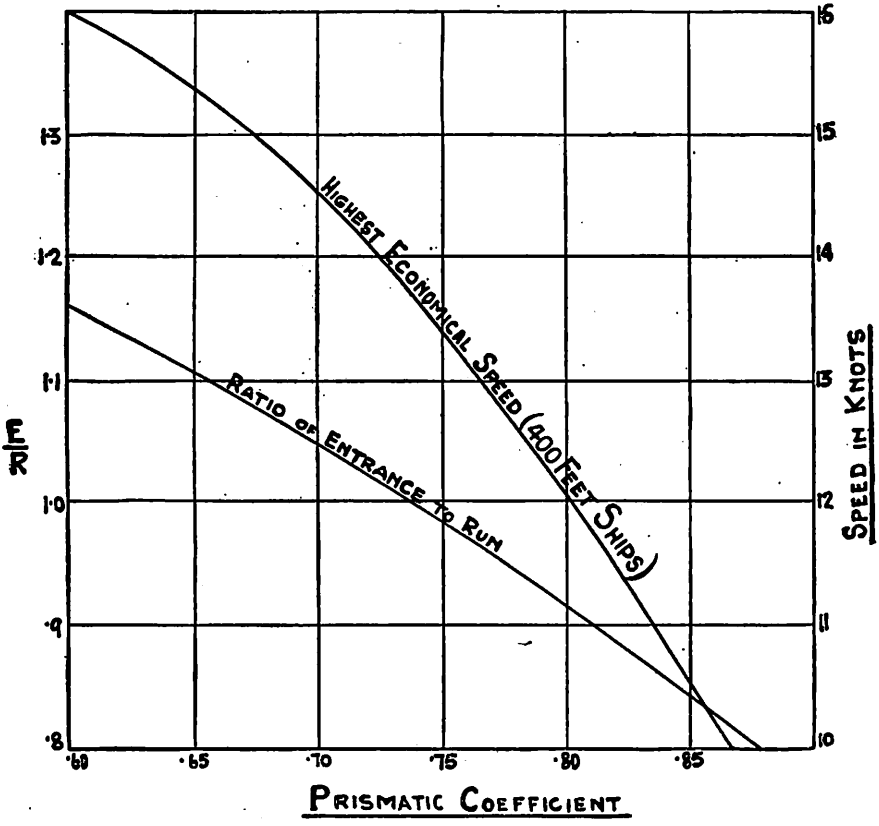


PLATE 25.

Table 8.

Set.	Tons. Displacement.	Coefficients. Block.	Coefficients. Prismatic.	Ratio. Length of Entrance / Run		Results at Various Speeds.										Model
					$\frac{V}{\sqrt{L}}$	·405	·446	·486	·527	·568	·608	·649	·690	·73	·77	
					knots	8·11	8·92	9·73	10·54	11·36	**12·17**	12·9	13·80	14·6	15·4	
E	11220	·803	·819	·602	E.H.P.	467	626	861	1138	1536	2090	2910	4310	5400	7400	19 E
	11232	·804	·820	·738	,,	488	643	848	1116	1466	1973	2780	3880	4960	7000	19 D
	11259	·805	·821	·999	,,	489	649	855	1104	1448	1847	2658	3570	4390	6740	19 B
	11266	·8055	·822	1·247	,,	514	680	895	1134	1520	1940	2660	3585	4332	6850	24 B
	11276	·806	·822	1·653	,,	582	803	1062	1379	1850	2388	3276	4086	4812	8781	24 A
					$\frac{V}{\sqrt{L}}$	·440	·480	·52	·56	·60	·64	·680	·720	·760	·800	
					knots	8·81	9·61	10·41	11·21	12·01	12·81	13·61	**14·41**	15·21	16·01	
D	10268	·735	·75	·599	E.H.P.	518	669	873	1099	1405	1804	2426	3349	4796	6605	23 A
	10293	·736	·751	·800	,,	507	667	866	1111	1373	1712	2116	2830	4112	5710	23 B
	10310	·739	·754	1·00	,,	521	680	867	1131	1400	1727	2242	3225	4330	5190	19 A
	10329	·7395	·755	1·26	,,	525	686	884	1128	1426	1759	2138	2640	3348	4885	23 C
	10346	·740	·755	1·668	,,	557	743	934	1198	1540	1900	2404	3035	4114	5510	23 C
					$\frac{V}{\sqrt{L}}$	·475	·553	·593	·633	·672	·711	·751	·790	·83	·87	
					knots	9·5	11·06	11·86	12·66	13·44	14·22	15·02	**15·81**	16·6	17·4	
C	9586	·686	·701	·554	E.H.P.	651	1089	1373	1671	2010	2488	3200	4314	5800	7800	18 D
	9581	·686	·7005	·667	,,	658	1053	1360	1663	1965	2362	2900	3689	4760	6650	18 C
	9570	·6855	·70	·905	,,	649	1115	1289	1632	1940	2222	2672	3192	3838	5340	18 A
	9564	·685	·6996	1·212	,,	641	1030	1278	1630	1985	2285	2800	3400	3920	5150	20 A
	9552	·6845	·699	1·627	,,	660	1080	1340	1685	2114	2480	3039	3983	4744	5830	22 A
					$\frac{V}{\sqrt{L}}$	·580	·618	·656	·695	·733	·773	·811	·85	·89	·927	
					knots	11·6	12·36	13·12	13·9	14·67	15·46	**16·22**	17·0	17·78	18·54	
B	*8465*	·606	·6195	·566	E.H.P.	...	1356	...	1896	2215	2740	3475	4555	6105	...	17 B
	8460	·606	·6195	·684	,,	...	1278	...	1912	2198	2580	3113	3981	5300	7065	17 A
	8450	·605	·6176	·904	,,	1067	1300	1586	1963	2350	2682	3108	3770	4754	6100	14 B
	8434	·603	·615	1·214	,,	1059	1281	1552	1860	2272	2851	3375	3850	4655	5890	16 B
	8422	·603	·615	1·624	,,	...	1291	...	1860	2264	2848	3373	3840	4670	5886	16 D
					$\frac{V}{\sqrt{L}}$	·379	·454	·568	·643	·757	·833	·870	...	...	...	
					knots	7·58	9·09	11·36	12·87	15·15	16·66	**17·41**	...	...	...	
A	7480	·589	·601	·756	E.H.P.	283	484	907	1354	2225	3352	4270	...	...	...	14 C
	7415	·584	·596	1·0	,,	271	456	875	1260	2200	3055	3790	...	...	...	14 A
	7374	·581	·593	1·323	,,	272	456	865	1271	2205	2989	3685	...	...	...	29 A
	7345	·579	·591	1·681	,,	289	494	950	1370	2440	3350	4080	...	...	...	16 C

Heavy Types indicate suitable trial trip speeds.

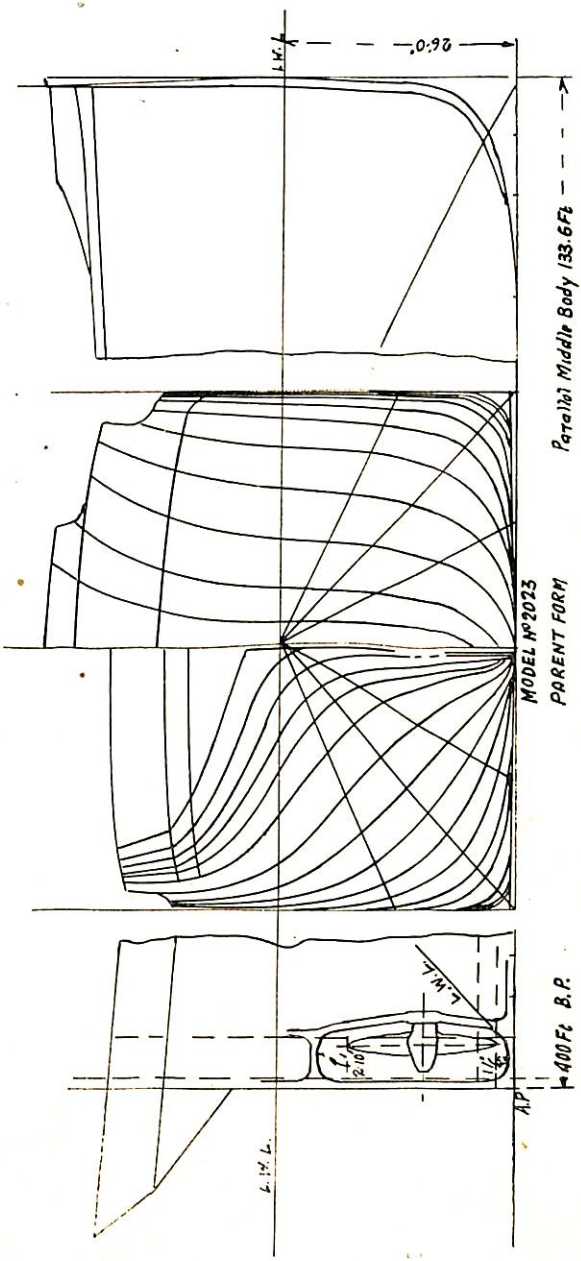

0.98
Parallel Middle Body 133.6Ft
MODEL N°2023
PARENT FORM
400 Ft B.P.
A.P.

PLATE 26.

Plate No. 25, based on these experiments, will enable a close approximation to be made to this ratio. These experiments were all carried out on bare-towed models.

Recently, M'Entee in the States and Semple at Clydebank have carried out a series of experiments on self-propelled models for 400 ft. cargo vessels, ranging from ·72 to ·77 block coefficient.

Plate 26 gives the body plan of the parent model 2023, used by McEntee in his experiments. Plate 27 gives the sectional area curves of entrance and run, also diagonals and W.L.'s, as shown on Plate 26 in the form of curves, in a form which will be found very useful by the designer who may wish to make use of this very good model. An explanation of how to use the diagram is shown underneath the curves. By means of it the other models used by McEntee can be obtained. They were formed by varying the fore and aft position of the parallel body, thus either shortening the entrance and lengthening the run or *vice-versa*.

Plate 28 gives the results obtained by McEntee in the form of curves which are self-explanatory. Briefly they indicate that for a ship of the fulness of model 2023, the best position for the parallel body is with two-thirds of it forward of midships and one-third aft, giving a centre of buoyancy about $2\frac{1}{2}$ per cent. forward of amidships. These results were confirmed by Semple in his ' G ' model of practically the same coefficient, and even in his finer series ' M,' although the best position was amidships, still with the C.B. 2 per cent. forward there was very little increase in resistance. As Semple's results contain a wealth of information, his complete findings are given here in tabular form in Table No. 9, and his wake values in Plate 29. These wake values are plotted to a base of prismatic coefficient aft and illustrate how sensitive this value is to the fulness or fineness of the after end. An explanation of the wake will be found in a later heading.

Curve of Areas and Prismatics of Entrance and Run.

Before proceeding to discuss this section it would be well at this point to explain in detail the models used by Mr. Baker in his 1914 paper, which will have most bearing on this section.

Baker's models were divided into three sets, each having a fixed proportion of parallel body inserted amidships between equal entrances and runs. The percentages of parallel body used were 10·45, 30, and 50. In each set five different entrances were tried with one run, and five different runs with one entrance. Three of the entrances were of different shape, but of same prismatic coefficient, whilst three were of different prismatics, the same applying to the runs. The load water-lines were of the same character as the curve of areas, as a glance at Plate 30 will show. This Plate give the sectional areas and load water-lines used, with their corresponding prismatics.

TABLE 9.

DIMENSIONS OF CARGO SHIPS A TO D.

—	Length in Feet.	Breadth in Feet.	Draught in Feet.	Displacement in Tons.	δ	ϕ_f	ϕ_a	β	Long. Centre of Buoyancy from Amidships.
"A"	400	53 33	24	10,752	0·737	0·747	0·757	0·980	0·25 per cent. L. aft.
"B"	400	53·33	24	11,045	0·755	0·768	0·774	0·980	0·25 per cent. L. aft.
"C"	400	53·33	24	11,337	0·775	0·788	0·796	0·980	0·25 per cent. L. aft.
"D"	400	53·33	24	11,629	0·795	0·807	0·816	0·980	0·25 per cent. L. aft.

TABLES OF DIMENSIONS, COEFFICIENTS, AND RESULTS OF THE VARIOUS MODELS TO 400 FT. LENGTH.

δ = Block coefficient. ϕ_f = Prismatic coefficient forward. ϕ_a = Prismatic coefficient aft.

β = Mid Area coefficient. (C) Values on base of (L).

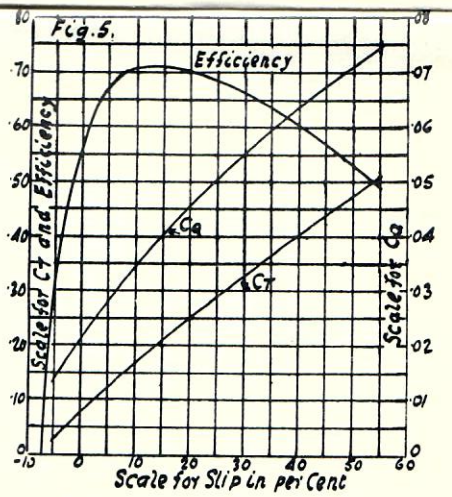
Where (L) $= 1{\cdot}055 \dfrac{V}{\sqrt{L}}$ E.H.P. $= (C) \dfrac{\triangle^{\frac{2}{3}} V^3}{427.1}$

Length, Ft.	Breadth, Ft.	Draught, Ft.	Displacement in Tons.	δ	ϕ_f	ϕ_a	β	(L) 0·48	0·50	0·52	0·54	0·56	0·58	0·60	0·62	0·64	0·66	0·68	0·70
400	53·33	17·70	7,714	0·715	0·734	0·735	0·974	0·693	0·697	0·700	0·703	0·714	0·730	0·750	0·766	0·778	0·786	0·790	0·790
	—	19·60	8,624	0·721	0·739	0·742	0·976	0·585	0·688	0·691	0·696	0·704	0·720	0·740	0·758	0·770	0·779	0·784	0·785
"A"	—	21·70	9,642	0·729	0·743	0·750	0·978	0·678	0·681	0·682	0·686	0·696	0·710	0·730	0·749	0·760	0·770	0·776	0·780
	—	24·00	10,780	0·737	0·747	0·757	0·980	0·670	0·672	0·674	0·677	0·686	0·700	0·720	0·740	0·755	0·765	0·772	0·775
	—	26·50	12,050	0·746	0·753	0·766	0·981	0·660	0·662	0·663	0·664	0·673	0·687	0·707	0·729	0·746	0·758	0·765	0·769
400	53·33	17·65	7,896	0·734	0·754	0·756	0·972	0·735	0·740	0·745	0·753	0·768	0·786	0·805	0·825	0·838	0·846	0·851	0·853
	—	19·55	8,827	0·741	0·759	0·761	0·975	0·720	0·723	0·729	0·736	0·749	0·763	0·785	0·803	0·819	0·829	0·835	0·839
"B"	—	21·65	9,870	0·748	0·763	0·767	0·978	0·701	0·707	0·710	0·719	0·730	0·745	0·764	0·784	0·798	0·808	0·815	0·820
	—	24·00	11,034	0·755	0·768	0·774	0·980	0·685	0·691	0·694	0·698	0·709	0·723	0·743	0·764	0·780	0·792	0·799	0·804
	—	26·55	12,332	0·762	0·772	0·782	0·981	0·670	0·672	0·674	0·679	0·687	0·701	0·721	0·743	0·760	0·773	0·784	0·791
400	53·33	17·70	8,160	0·756	0·776	0·778	0·974	0·770	0·777	0·781	0·790	0·805	0·827	0·847	0·863	0·875	0·883	0·890	0·898
	—	19·57	9,093	0·762	0·780	0·784	0·976	0·756	0·762	0·768	0·777	0·791	0·812	0·835	0·852	0·865	0·870	0·878	0·885
"C"	—	21·65	10,182	0·772	0·788	0·791	0·978	0·742	0·748	0·750	0·760	0·775	0·795	0·820	0·838	0·852	0·861	0·868	0·871
	—	24·00	11,352	0·775	0·788	0·796	0·980	0·730	0·733	0·738	0·745	0·760	0·780	0·805	0·824	0·838	0·848	0·853	0·858
	—	26·60	12,694	0·783	0·793	0·804	0·981	0·717	0·721	0·723	0·732	0·747	0·766	0·791	0·810	0·825	0·835	0·840	0·845
400	53·33	17·65	8,330	0·774	0·792	0·798	0·974	0·790	0·798	0·803	0·810	0·826	0·846	0·868	0·885	0·900	0·911	0·921	0·932
	—	19·55	9,304	0·781	0·797	0·803	0·976	0·781	0·790	0·795	0·801	0·815	0·835	0·859	0·878	0·892	0·904	0·913	0·924
"D"	—	21·65	10,387	0·787	0·801	0·809	0·978	0·771	0·780	0·784	0·792	0·807	0·827	0·850	0·868	0·883	0·895	0·905	0·916
	—	24·00	11,630	0·795	0·807	0·816	0·980	0·764	0·771	0·776	0·784	0·800	0·820	0·843	0·861	0·876	0·887	0·896	0·907
	—	26·62	13,006	0·802	0·809	0·882	0·981	0·757	0·763	0·769	0·777	0·793	0·813	0·835	0·854	0·870	0·881	0·891	0·901
400	52·00	17·52	8,084	0·776	0·819	0·766	0·979	0·929	0·945	0·969	1·004	1·050	1·084	1·099	1·104	1·135	1·232	1·325	1·375
	—	19·46	9,038	0·781	0·822	0·770	0·981	0·913	0·927	0·950	0·980	1·020	1·054	1·070	1·078	1·120	1·221	1·305	1·352
"E"	—	21·67	10,104	0·787	0·826	0·775	0·983	0·902	0·914	0·935	0·963	1·004	1·035	1·050	1·064	1·114	1·212	1·292	1·332
	—	24·00	11,296	0·792	0·829	0·781	0·984	0·898	0·910	0·929	0·956	0·992	1·024	1·040	1·057	1·109	1·203	1·281	1·320
	—	26·63	12,630	0·798	0·832	0·786	0·986	0·902	0·914	0·935	0·963	1·004	1·035	1·050	1·004	1·114	1·212	1·292	1·332
400	52·00	18·29	8,159	0·750	0·811	0·721	0·979	0·749	0·753	0·762	0·773	0·787	0·800	0·808	0·817	0·824	0·838	0·860	0·885
	—	20·28	9,121	0·757	0·814	0·729	0·981	0·714	0·719	0·728	0·740	0·753	0·768	0·781	0·794	0·805	0·821	0·843	0·870
"F"	—	22·45	10,198	0·764	0·818	0·737	0·983	0·688	0·691	0·700	0·711	0·725	0·740	0·755	0·769	0·784	0·802	0·828	0·847
	—	24·88	11,402	0·772	0·823	0·745	0·984	0·677	0·680	0·685	0·692	0·703	0·715	0·729	0·744	0·762	0·784	0·812	0·845
	—	27·50	12,747	0·780	0·828	0·754	0·986	0·672	0·675	0·678	0·682	0·689	0·697	0·708	0·722	0·742	0·768	0·800	0·835
400	53·33	17·50	8,061	0·755	0·818	0·724	0·979	0·710	0·716	0·728	0·742	0·758	0·770	0·780	0·790	0·801	0·818	0·835	0·852
	—	19·50	9,012	0·758	0·819	0·727	0·981	0·681	0·689	0·700	0·715	0·730	0·745	0·755	0·768	0·781	0·804	0·827	0·850
"G"	—	21·66	10,076	0·763	0·820	0·732	0·983	0·666	0·670	0·680	0·692	0·705	0·717	0·730	0·741	0·760	0·788	0·820	0·849
	—	24·00	11,265	0·770	0·824	0·740	0·984	0·650	0·655	0·662	0·675	0·686	0·698	0·708	0·718	0·735	0·765	0·806	0·847
	—	26·54	12,575	0·779	0·831	0·751	0·985	0·640	0·642	0·650	0·661	0·674	0·682	0·698	0·694	0·708	0·740	0·795	0·845
400	53·33	17·50	8,061	0·755	0·772	0·770	0·979	0·800	0·805	0·821	0·850	0·875	0·892	0·902	0·925	0·952	0·947	0·986	0·993
	—	19·50	9,012	0·758	0·774	0·772	0·981	0·800	0·805	0·821	0·850	0·875	0·892	0·902	0·926	0·958	0·982	0·995	1·002
"H"	—	21·66	10,076	0·763	0·777	0·776	0·983	0·800	0·805	0·821	0·850	0·875	0·892	0·902	0·928	0·963	0·990	1·005	1·010
	—	24·00	11,265	0·770	0·782	0·782	0·984	0·800	0·805	0·821	0·850	0·875	0·892	0·902	0·930	0·969	1·000	1·018	1·022
	—	26·54	12,575	0·779	0·789	0·791	0·985	0·800	0·805	0·821	0·850	0·875	0·882	0·902	0·934	0·975	1·010	1·030	1·036
400	53·33	17·50	8,061	0·755	0·723	0·819	0·979	1·120	1·120	1·130	1·141	1·155	1·175	1·205	1·252	1·305	1·335	1·366	1·415
	—	19·50	9,012	0·758	0·725	0·821	0·981	1·120	1·122	1·135	1·150	1·169	1·190	1·220	1·265	1·313	1·340	1·373	1·423
"K"	—	21·66	10,076	0·763	0·729	0·824	0·983	1·113	1·139	1·148	1·169	1·190	1·213	1·250	1·295	1·330	1·350	1·380	1·430
	—	24·00	11,265	0·770	0·736	0·829	0·984	1·112	1·155	1·173	1·200	1·218	1·246	1·290	1·339	1·362	1·374	1·389	1·463
	—	26·54	12,575	0·779	0·744	0·835	0·985	1·112	1·186	1·212	1·240	1·255	1·295	1·375	1·403	1·413	1·415	1·422	1·455
400	53·33	17·70	7,533	0·699	0·768	0·660	0·979	0·690	0·690	0·693	0·700	0·713	0·727	0·739	0·748	0·753	0·759	0·764	0·772
	—	19·58	8,422	0·706	0·771	0·668	0·982	0·680	0·680	0·685	0·693	0·705	0·719	0·730	0·740	0·747	0·751	0·760	0·769
"L"	—	21·69	9,416	0·713	0·774	0·676	0·983	0·670	0·670	0·678	0·686	0·698	0·711	0·723	0·732	0·740	0·745	0·753	0·765
	—	24·00	10,528	0·720	0·778	0·685	0·984	0·665	0·665	0·671	0·679	0·690	0·703	0·714	0·722	0·730	0·736	0·745	0·760
	—	26·51	11,770	0·728	0·783	0·696	0·985	0·660	0·660	0·665	0·673	0·683	0·695	0·706	0·714	0·720	0·728	0·739	0·754
400	53·33	17·70	7,533	0·699	0·714	0·713	0·979	0·690	0·690	0·695	0·704	0·716	0·725	0·735	0·741	0·747	0·749	0·750	0·751
	—	19·58	8,422	0·706	0·720	0·719	0·981	0·670	0·670	0·678	0·685	0·700	0·712	0·723	0·732	0·740	0·743	0·745	0·746
"M"	—	21·69	9,416	0·713	0·725	0·726	0·983	0·655	0·655	0·660	0·672	0·687	0·700	0·712	0·722	0·730	0·735	0·739	0·743
	—	24·00	10,528	0·720	0·730	0·734	0·984	0·639	0·639	0·644	0·655	0·670	0·685	0·700	0·710	0·720	0·728	0·773	0·740
	—	26·51	11,770	0·728	0·736	0·743	0·985	0·622	0·622	0·630	0·638	0·654	0·670	0·685	0·699	0·707	0·715	0·725	0·737
400	53·33	17·70	7,533	0·699	0·664	0·674	0·979	0·810	0·610	0·810	0·810	0·812	0·815	0·820	0·823	0·829	0·835	0·843	0·853
	—	19·58	8,422	0·706	0·671	0·768	0·981	0·794	0·794	0·795	0·795	0·798	0·802	0·810	0·820	0·831	0·845	0·859	0·875
"N"	—	21·69	9,416	0·713	0·678	0·773	0·983	0·774	0·774	0·775	0·778	0·781	0·791	0·804	0·819	0·834	0·853	0·873	0·896
	—	24·00	10,528	0·712	0·685	0·799	0·984	0·757	0·757	0·759	0·763	0·770	0·780	0·797	0·818	0·840	0·863	0·890	0·915
	—	26·51	11,770	0·728	0·692	0·786	0·985	0·745	0·745	0·748	0·750	0·758	0·771	0·790	0·817	0·845	0·876	0·908	0·985

DIMENSIONS OF CARGO SHIPS G TO N.

—	Length in Feet.	Breadth in Feet.	Draught in Feet.	Displacement in Tons.	δ	ϕ_f	ϕ_a	β	Long. Centre of Buoyancy from Amidships.
"G"	400	53·33	24	11,265	0·770	0·824	0·740	0·984	2 per cent. L. ford.
"H"	400	53·33	24	11,265	0·770	0·782	0·782	0·984	—
"K"	400	53·33	24	11,265	0·770	0·736	0·829	0·984	2 per cent. L. aft.
"L"	400	53·33	24	10,528	0·720	0·778	0·685	0·984	2 per cent. L. ford.
"M"	400	53·33	24	10,528	0·720	0·730	0·734	0·984	—
"N"	400	53·33	24	10,528	0·720	0·685	0·779	0·984	2 per cent. L. aft

McEntee's Experiments on the Most Suitable Fore and Aft Position of the Parallel Body for a vessel of ·772 Block.

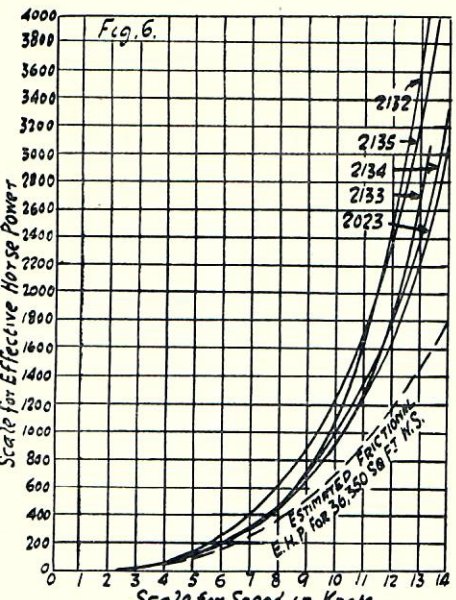


Curves of Propellor Characteristics

Pitch ratio	·889
Ratio Projected area to disc area	·266
Mean width ratio	·200
Blade thickness fraction	·040

$$C_Q = \frac{Q}{n^2 p^3 d^2} \qquad C_T = \frac{T}{n^2 p^2 d^2}$$

d = diameter in feet
p = pitch in feet
n = revolutions per second
T = thrust in pounds
Q = torque in pound-feet.



Curves of Effective Horse Power for 400 Ft. Cargo Ship
With variable location of parallel middle body
Beam = 57·3 ft., draft = 26 ft., displacement = 13,137 tons
Length of parallel middle body = 133·6 ft or 33·4 per cent of length

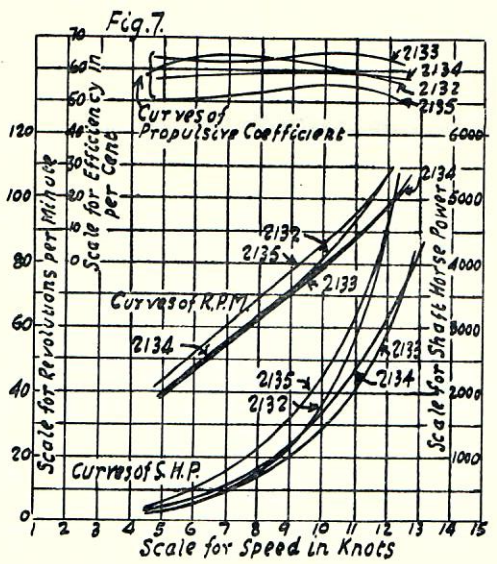


Fig.7.
Curves of Propulsive Coefficient
Scale for Efficiency in per Cent
Curves of R.P.M.
Curves of S.H.P.
Scale for Revolutions per Minute
Scale for Shaft Horse Power
Scale for Speed in Knots

Curves of Shaft Horse Power R.P.M., and Propulsive Coefficient for 400-Ft. Cargo Ship.
With variable location of parallel middle body
Breadth = 57·3 ft., draft = 26 ft., displacement = 13,137 tons
Length of parallel middle body = 133·6 ft or 33·4 per cent. of total length

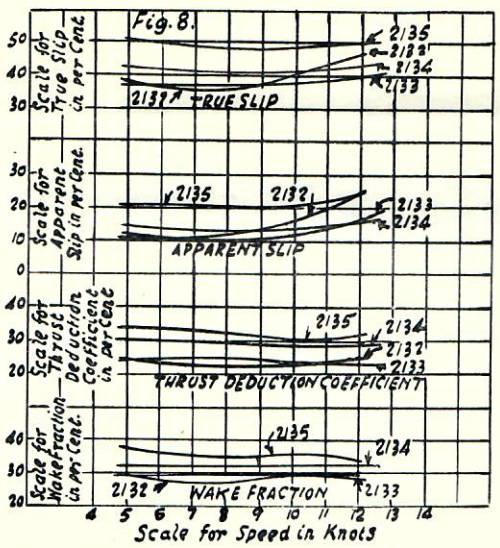


Fig.8.
TRUE SLIP
APPARENT SLIP
THRUST DEDUCTION COEFFICIENT
WAKE FRACTION
Scale for True Slip in per Cent
Scale for Apparent Slip in per Cent
Scale for Thrust Deduction Coefficient in per Cent
Scale for Wake Fraction in per Cent
Scale for Speed in Knots

Curves of Wake Fraction Thrust Deduction Coefficient, True Slip and Apparent Slip for 400-Ft. Cargo Ship
Variable location of parallel middle body
Beam = 57·3 ft., draft = 26 ft., displacement = 13,137 tons.
Length of parallel middle body = 133·6 ft. or 33·4 per cent. of length.

	Centre of Parallel Middle Body from F.P. in p.c. of Length	Length of Entrance in Beam	Length of Run in Beam	Appendages	Trim
2	31·30 p.c.	1·02	3·81	Stern frame and rudder	E.K
3	38·46 p.c	1·52	3·13	do	"
3	46·84 "	2·10	2·54	"	"
4	53·33 "	2·56	2·09	"	"
5	60·50 "	3·06	1·59	"	"

Model No.	Centre of Parallel Middle Body from F.P. in p.c. of Length.	Length of Entrance in Beams	Length of Run in Beams	Appendages	Trim
2132	31·30 p.c	1·02	3·63	Stern frame and Rudder	E.K
2133	38·46 "	1·52	3·13	do	"
2134	53·33 "	2·56	2·09	"	"
2135	60·60 "	3·06	1·51	"	"

Model No	Centre of Parallel Middle Body from F.P. in p.c. of Length	Length of Entrance in Beam	Length of Run in Beam	Appendages	Trim
2132	31·30 p.c.	1·02	3·63	Stern frame and rudder	E.K.
2133	38·46 "	1·52	3·13	do	"
2134	53·33 "	2·56	2·09	"	"
2135	60·50 "	3·06	1·61	"	"

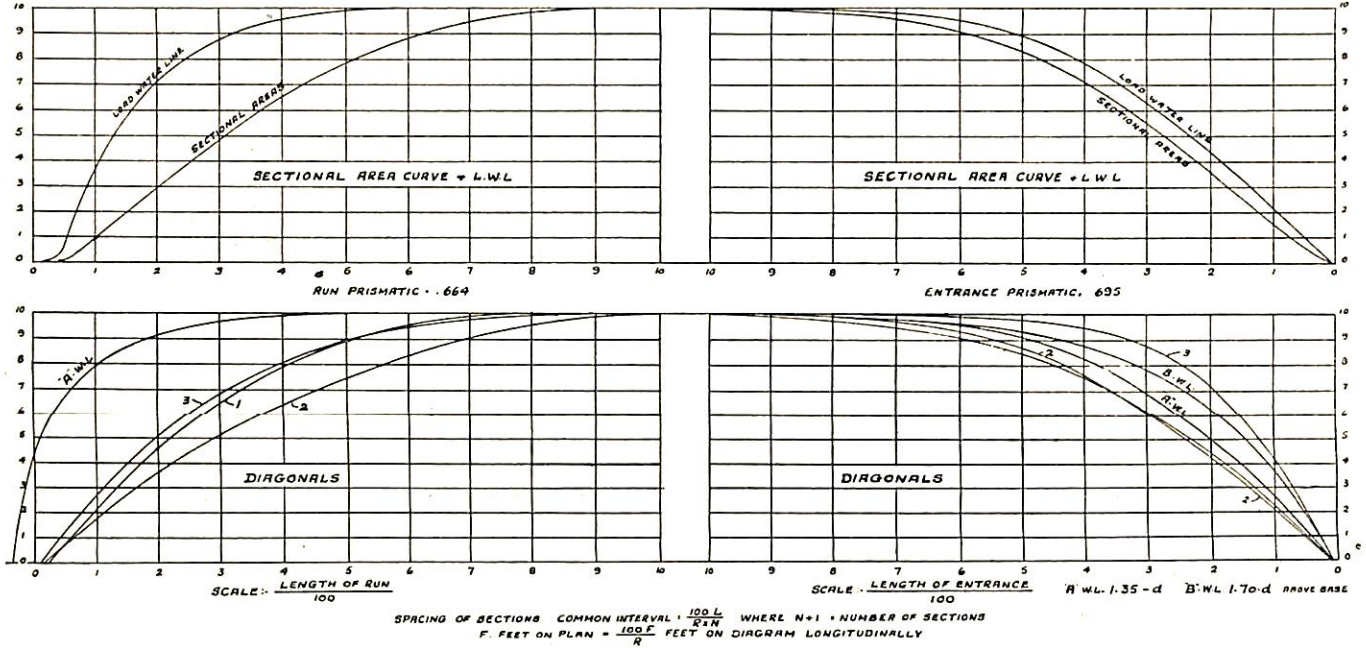

STANDARD LINES DIAGRAM
EXPERIMENTAL TANK MODEL - Mc ENTEE'S 2032
BASIS SHIP - 400'-0" x 57.3" x 26'-0" DRAFT. - ENTRANCE 120.51' - RUN 145.84 - PARALLEL BODY 133.65'
PRISMATIC COEFF. .788 BLOCK COEFF. .7716 MIDSHIP COEFF. .979 Δ. 13137 C.B. 5.4' FWD
LOAD WATER LINE
SECTIONAL AREAS
SECTIONAL AREA CURVE + L.W.L
RUN PRISMATIC . . 664
ENTRANCE PRISMATIC. 695
DIAGONALS
B.WL.
A.WL.
SCALE :- LENGTH OF RUN / 100
SCALE . LENGTH OF ENTRANCE / 100
A WL. 1.35 - d
B.WL 1.70-d ABOVE BASE
SPACING OF SECTIONS COMMON INTERVAL = 100 L / R+N WHERE N+1 = NUMBER OF SECTIONS
F. FEET ON PLAN = 100 F / R FEET ON DIAGRAM LONGITUDINALLY

PLATE 27.

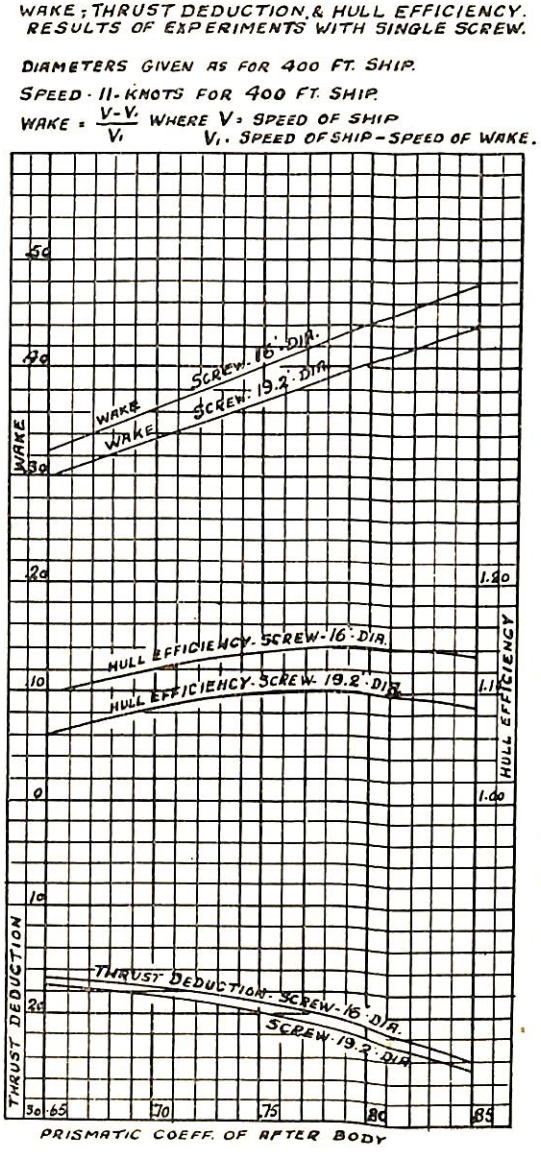

WAKE; THRUST DEDUCTION, & HULL EFFICIENCY.
RESULTS OF EXPERIMENTS WITH SINGLE SCREW.
DIAMETERS GIVEN AS FOR 400 FT. SHIP.
SPEED - 11 - KNOTS FOR 400 FT. SHIP.
WAKE = (V-V1)/V1 WHERE V = SPEED OF SHIP
V1 = SPEED OF SHIP - SPEED OF WAKE.
WAKE
.50
.40
.30
.20
.10
0
.10
.20
.30
WAKE SCREW-16'-DIA.
WAKE SCREW-19.2'-DIA.
HULL EFFICIENCY
1.20
1.10
1.00
HULL EFFICIENCY-SCREW-16'-DIA.
HULL EFFICIENCY-SCREW-19.2'-DIA.
THRUST DEDUCTION
THRUST DEDUCTION-SCREW-16'-DIA.
SCREW-19.2'-DIA.
.65
.70
.75
.80
.85
PRISMATIC COEFF. OF AFTER BODY

PLATE 29.

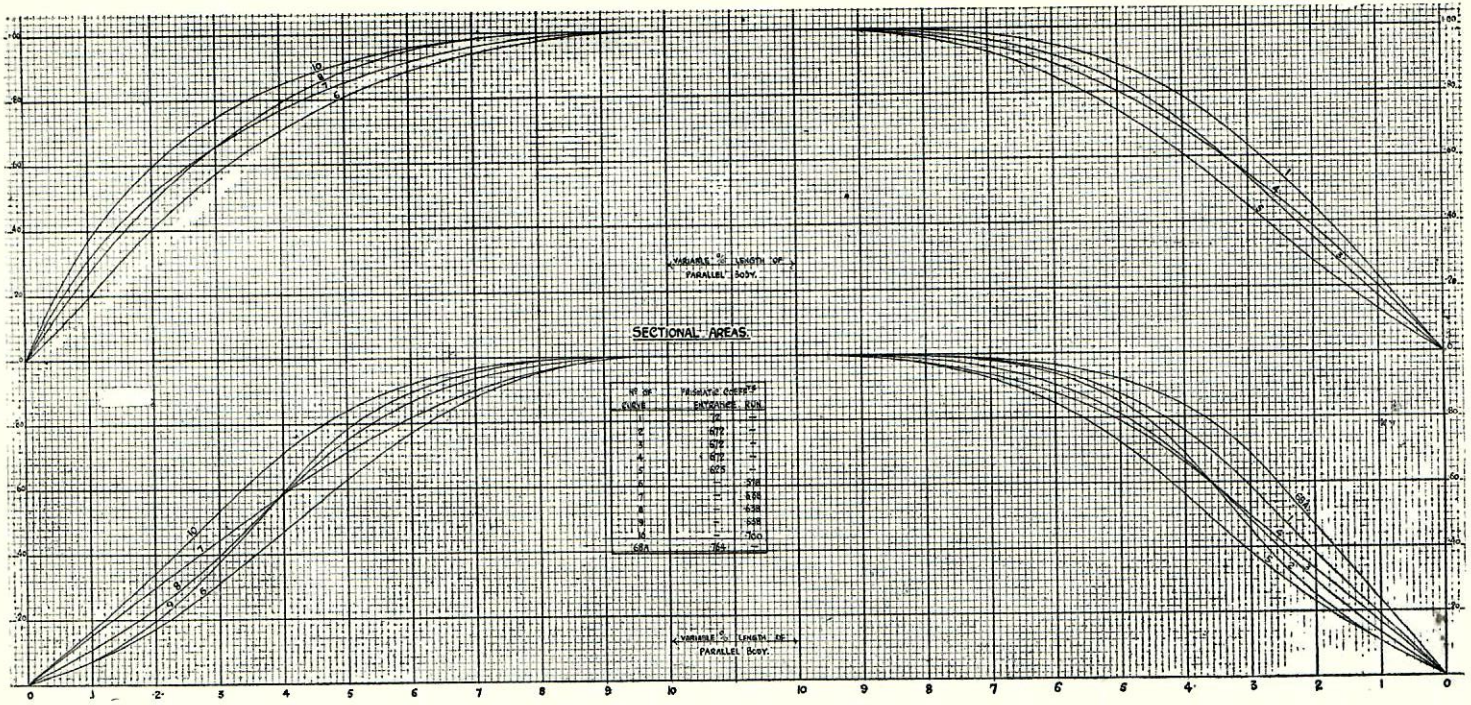

SECTIONAL AREAS.
VARIABLE % OF LENGTH OF PARALLEL BODY.
VARIABLE % OF LENGTH OF PARALLEL BODY.

PLATE 30.

The following Table gives the particulars of all the models brought to a common standard length of 400 feet.

Table 10.

Group F 10·45% parallel body, Group G 30%, Group H 50%.

$$\text{Length} = 7{\cdot}654 \times \text{Beam.} \qquad \text{Draught} = \frac{\text{Beam}}{2{\cdot}25}$$

Midship Section Coefficient = ·980.

Models.	Prismatics.					Remarks.
	Ent'ce.	Run.	Total Group F.	Total Group G.	Total Group H.	
1	·72		·712	·775	·850	
2	·672	All	·690	·758	·828	Straight line bow.
3	·672	·638	·690	·758	·828	Medium line bow.
4	·672		·690	·758	·828	Hollow line bow.
5	·625		·67	·741	·816	
6		·578	·664	·737	·812	
7	All	·638	·690	·758	·828	Straight line stern.
8	·672	·638	·690	·758	·828	Medium line stern.
9		·638	·690	·758	·828	Hollow line stern.
10		·70	·719	·780	·843	
68 A	·764	·638			·850	

Mr. Baker presented his results in the following form. One object of the experiments being to trace the cause of bad performances, the results were plotted with (C) values as ordinates to a base of (P) where $(P) = ·746 \frac{V}{\sqrt{P \times L}}$ (P) expresses the relation of the speed of the ship to the speed of a wave, having a length from crest to crest equal to P × L where P is prismatic coefficient. The position of the humps and hollows in the resistance curve depends on certain values of this (P), which are indicated on Plate 31, given as an example of Baker's mode of presentation.

Briefly stated, Baker's findings were as follows :—

Table 11.

Set.	Entrance.		Run.	
	Fineness of Entrance.	Shape of Entrance.	Fineness of Run.	Shape of Run.
F	5 better than 3 at all speeds, 3 better than 1 when (P) > ·6 H.E.V. (P) = ·75.	3 medium bow best over useful range of speeds. Straight best when (P) > ·75	6 best when (P) > ·65.	Straight 7 best up to (P) = ·7 hollow slightly better at higher speeds.
G	5 better than 3 when (P) > ·53, 3 better than 1 when (P) > ·577 H.E.V. (P) = 61.	Medium better for (P) between ·53 and ·62. Straight best at higher speeds.	10 always bad, 6 slightly better than 8 when (P) > ·55.	Straight and medium about equal. Hollow inferior.
H	5 better than 3 when (P) > ·45, 3 better than 1 when (P) > ·375 H.E.V. (P) = ·46.	Straight best, especially when (P) > ·45.	10 causes serious eddy-making. 6 better than 8.	Straight best. Any hollow causes eddy-making.

H.E.V. = Highest Economical Value.

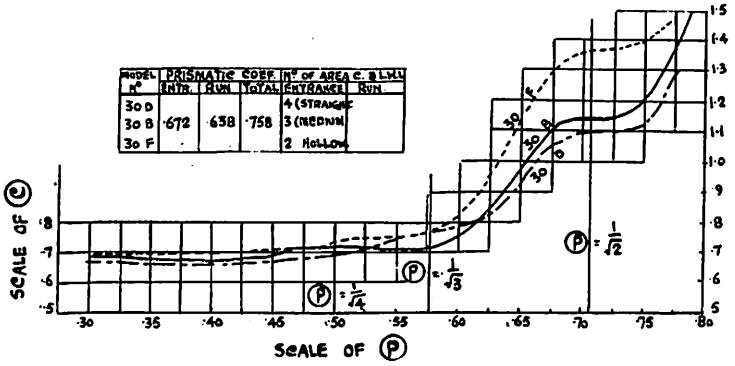


PLATE 31.

Sadler in America, in some experiments with a model of ·869 prismatic, found that a rounded form forward and a straight run aft gave the best results. (See Plate 44, F.8 series).

From the above analysis it seems to be desirable to adopt forward a hollow sectional area curve at fine prismatics, a medium hollow at the intermediate coefficients straight ended at about ·8 prismatic and slightly rounded about ·85 prismatic. Aft a gradual change from a medium hollow run at fine prismatics to a straight run for the intermediate and full.

The following notes by Mr. Baker are of interest :—" Generally speaking a somewhat full shoulder to the entrance is not detrimental if speed low, but a full shoulder to the run may result in increased power due to either eddy or divergent wave formation. (Semple confirms this in his paper with models C and H, where C is a fuller model than H and with worse position of parallel body but with much easier run. It is owing to this latter circumstance that the power is less than in H). Another point to note—do not cut away the after end of run to get a fine finish, but let the area curve be carried out with a fair curve to its end with no marked change in shape just before the body post. The slope of the tangent to the curve should avoid a quick change and its maximum slope to the base kept as small as possible."

Load Water Line.

As regards this important feature, Baker's conclusions are as follows :—

For all full vessels this should never be hollow or concave at entrance, but be slightly convex or straight. Where it runs into the parallel middle body it can be fairly blunt. As the speed increases the entrance angle must be made finer and the greater must

be the distance from the stem before turning into the parallel body. At low speeds (say 9 knots for 400 ft. ship) 60° can be permitted. At the after end, the angle between any tangent to the load water-line and the middle line of the ship should not exceed about 20° in order to avoid dragging dead water with the vessel. Should a greater angle than 20° become a necessity, the curve must be so drawn that the maximum slope is as far aft as possible, consistent with finishing at the rudder-post without any marked change in curvature or hollow in the curve. At low speeds a fine end aft, obtained by filling out in front of it, is quite as conducive to eddy-making as a full finish, as the stream lines tend to break up whenever the rate of expansion exceeds that given by a level boundary of 20° to 25°. It is here that the main propulsive benefit of a cruiser stern is obtained. With beamy ships or ships of high prismatic, a well-immersed cruiser stern enables a reasonable slope to be given to the load waterline and lines immediately below it, thus eliminating eddy formation in this area.

Transverse Sections.

Sadler's 1921 paper on " The influence of shape of tranverse sections upon the resistance of vessels of moderate speed " probably on the whole is the best and most definite guide on this matter.

The parent body plans and curve of sectional areas used by Sadler are shown in Plate 32 and indicate the changes in type of section used. They are based upon a vessel 425 B.P. × 56 feet beam, with a normal draft of 24 feet 9 inches, and a deep load draft of 27 feet 9 inches. It has a cruiser stern and a length on the deep load line of 435 feet.

Two parent forms were taken as follows :—

(1) A model with a fixed length of run with " medium " type of stern sections.

(2) A model with a fixed length of entrance and " medium " type of bow sections.

Each model was further modified in the following manner :—

Fixed run 40·5% L.B.P.	Five lengths of entrance from 23·7% to 48·5% L.B.P.	Each type with U, medium and V-shaped sections forward.
Fixed entrance 27% L.B.P.	Four lengths of run, from 24·3% to 48·6% L.B.P.	Each type with U. medium, and V-shaped sections aft.

The particulars of the parent form are given in the following Table, the parallel body being 32·5% of L.B.P. :—

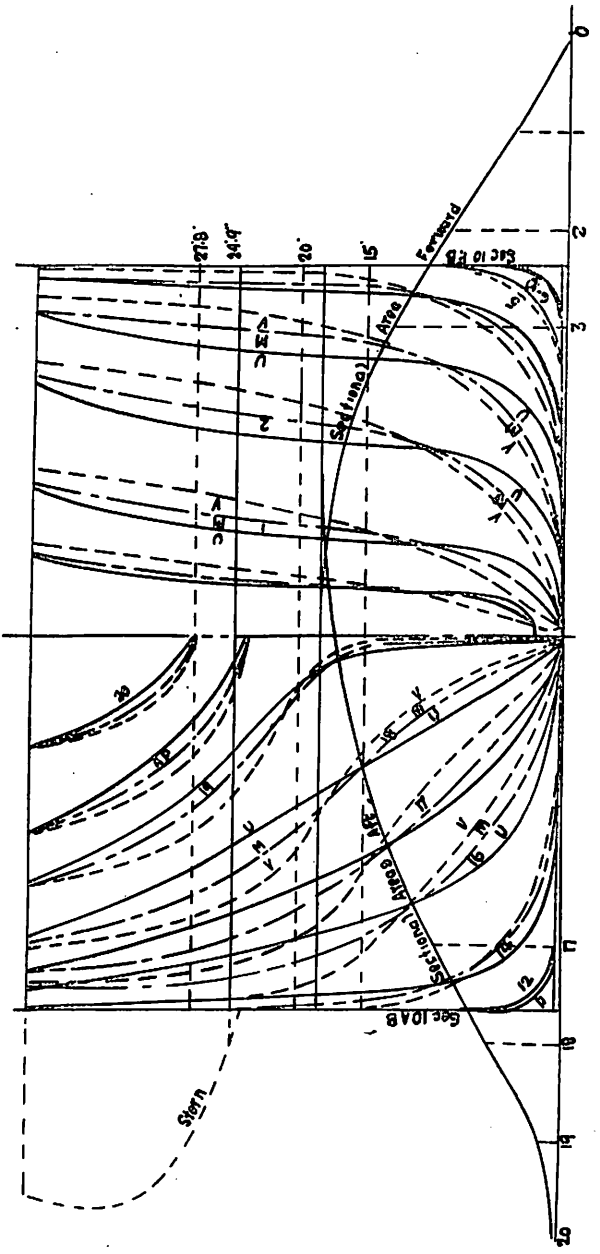

Forward
Sections
Stern
Sec 10 AB
Sec 10 FB
Sectional Areas
27.8
24.9
20
15
0
2
3
11
18
19
20

PLATE 32.

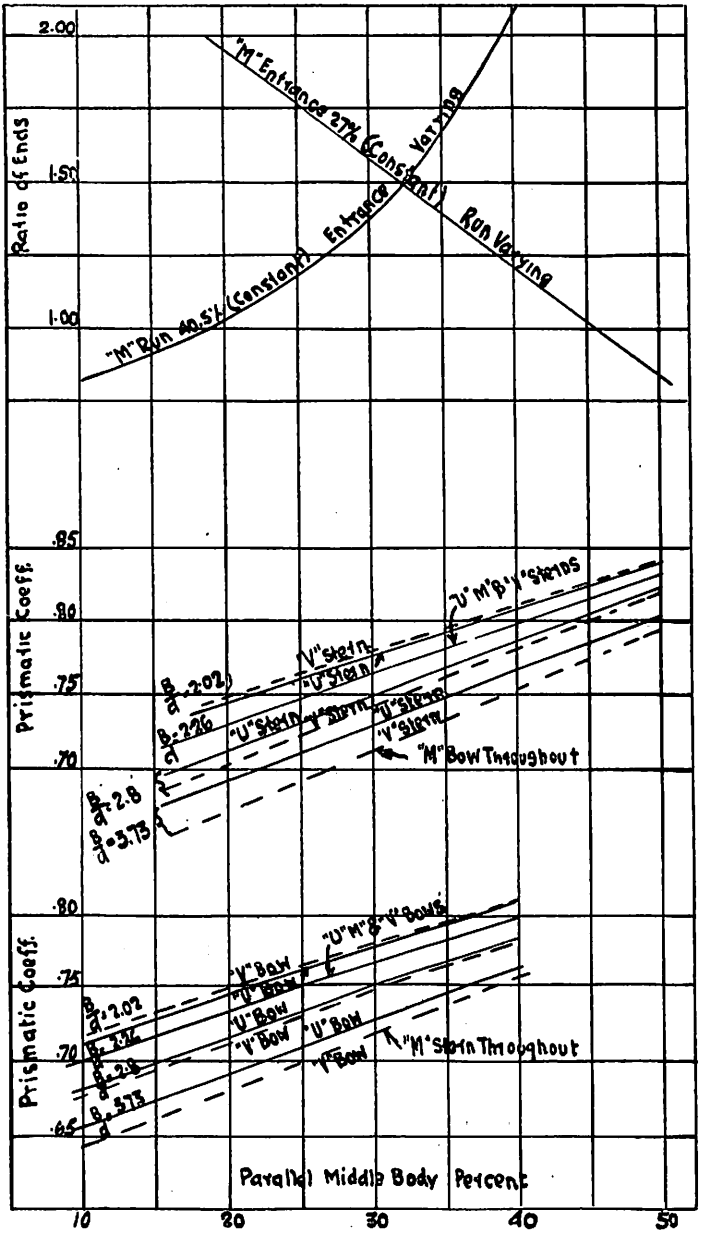

2.00
1.50
1.00
Ratio of Ends
"M" Entrance 27% (Constant) Varying
"M" Run 40.5% (Constant) Entrance Run Varying
.85
.80
.75
.70
Prismatic Coeff.
"U" M'B'y "V" Stems
"V" Stern
"U" Stern
"V" Stems
"M" Bow Throughout
.80
.75
.70
.65
Prismatic Coeff.
"U" M" & "V" Bows
"V" Bow
"U" Stern
"U" Bow
"M" Stern Throughout
Parallel Middle Body Percent
10
20
30
40
50

PLATE 33.

		Bow Sections varying.	Stern Sections varying.	B/d.
15 foot draft,	U,	·734	·727	3·73
	M,	·730	·728	
	V,	·727	·721	
20 foot draft,	U,	·756	·757	2·8
	M,	·754	·753	
	V,	·753	·750	
24-ft. 9-in. ,,	U,	·772	·772	2·26
	M,	·772	·772	
	V,	·772	·772	
27-ft. 9-in. ,,	U,	·785	·783	2·02
	M,	·786	·784	
	V,	·787	·785	

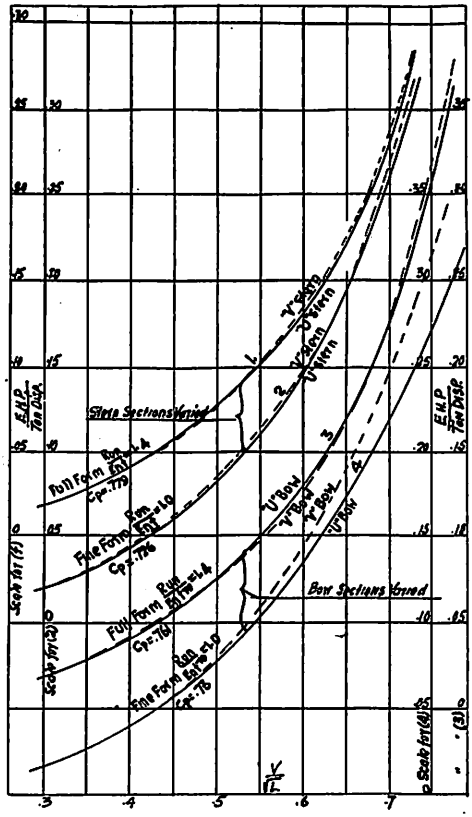


PLATE 34.

Plate 33 shows diagramatically the other variations of middle body and ends with prismatic coefficient. Plate 34, as a general comparison of V and U sections, shows the effect upon resistance for a full and a fine vessel with (1) stern sections, (2) bow sections varied. Generally with regard to bow sections, it is apparent that within the range of speed suitable, the V-shaped sections are best for the full form and U-shaped sections for the fine form. Plates 35 and 36 show the effect on resistance in terms of $\frac{V}{\sqrt{L}}$ due to modification of bow sections with a constant medium type of stern and modification of stern sections with constant medium type of bow, and also the influence of change of draft from light to load.

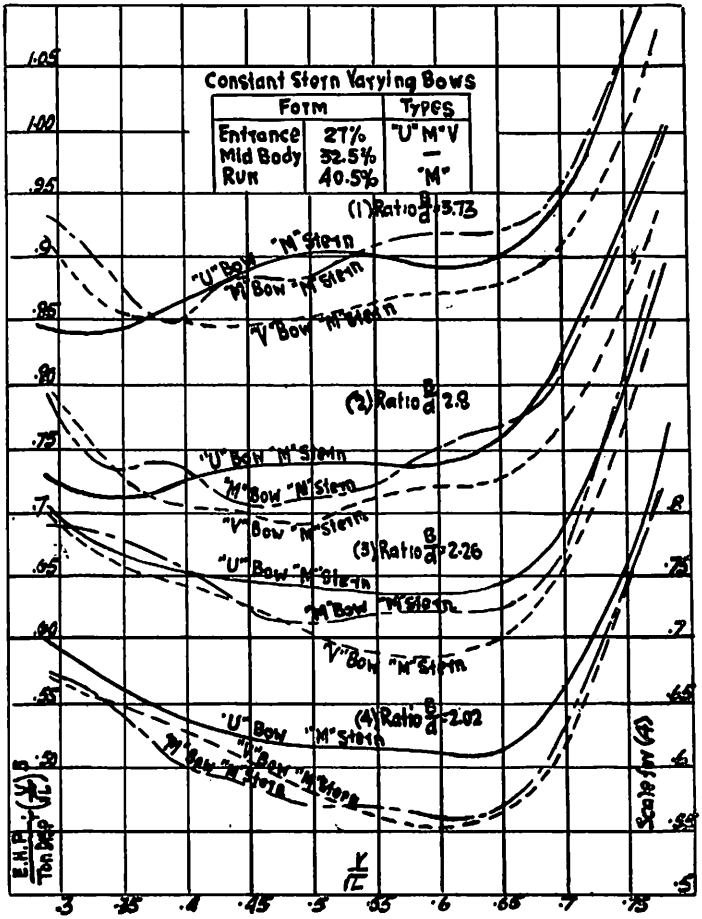


PLATE 35.

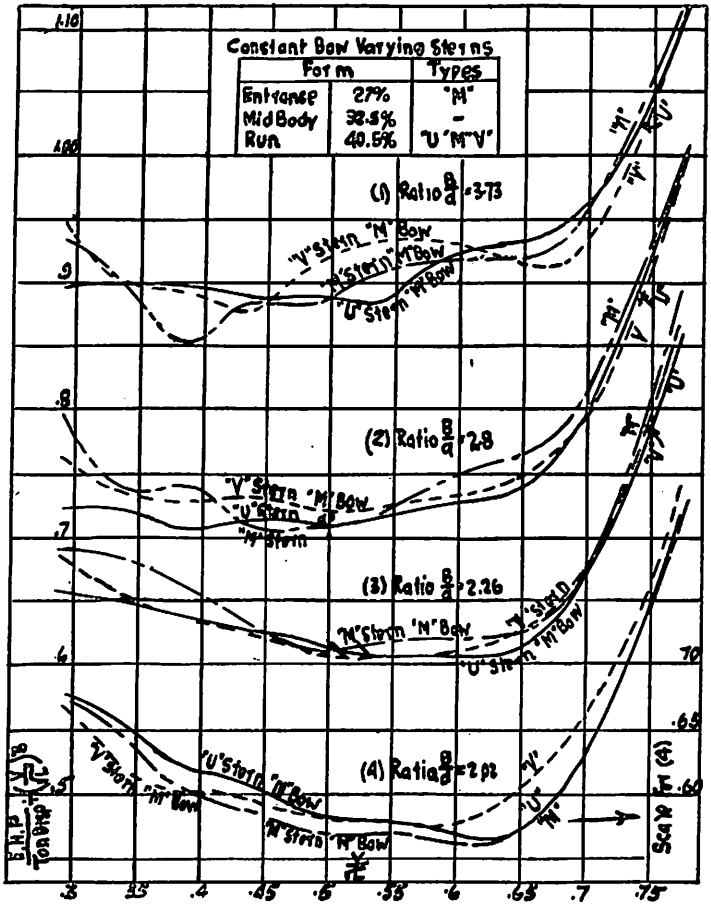


PLATE 36.

Table 12 gives the percentages of parallel body at which the resistance is a minimum for any given speed and the value of effective horse-power per ton at that speed. Cross curves can be made from this table showing the effect of these various changes for a selected speed length ratio. A diagram obtained in this manner is shown in Plate 37 for a speed length ratio of ·581.

The following example will illustrate how to use these results to find the effective horse-power for a similar ship. Prof. Sadler found that when the similar ship is only 10 to 12 per cent. longer or shorter than the model ship, the horse-power per ton can be obtained by multiplying the similar quantity for the model ship by $l^{\cdot 5}$ where l is the linear ratio between the model and the similar ship.

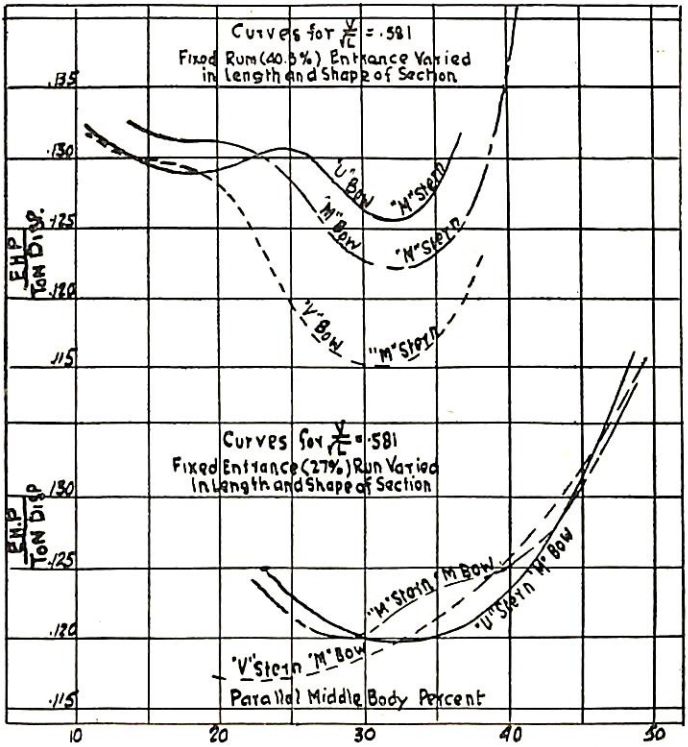


PLATE 37.

The E.H.P. of any ship taken as a model will be

$$\text{E.H.P.}_1 = (f_1 S_1 V_1^{2\cdot83} + R_w V_1) \times \cdot00307.$$

f_1 = coefficient of friction for model ship S_1 = wetted surface.
V_1 = speed in knots. R_w = wave resistance of model in pounds.

$$\text{then} \quad \frac{\text{E.H.P.}_2}{\text{Displ.}_2} = \frac{\text{E.H.P.}_1}{\text{Displ.}_1} \times l^{\cdot5}$$

The selection of the best type of section will depend upon—

(1) The speed length ratio.
(2) The fullness.
(3) The distribution of displacement longitudinally.
(4) The ratio of breadth to draught.

In the finer types of vessels of the merchant class and at speed length ratios over ·75 and not exceeding 1·0 the U-shaped bow sections accompanied with moderately V-shaped sections aft, *i.e.* sections not too full on the W.L. will give good results.

In the fuller types and at the speed length ratio of about ·6 or under, V-shaped bow sections accompanied with moderate V-stern sections as above will give satisfactory results.

If it is anticipated the vessel is to run at reduced draft for any appreciable percentage of her time, then the U-shaped bow sections lose their advantage and a compromise section will prove most satisfactory. Oil-carrying vessels are an illustration of this case.

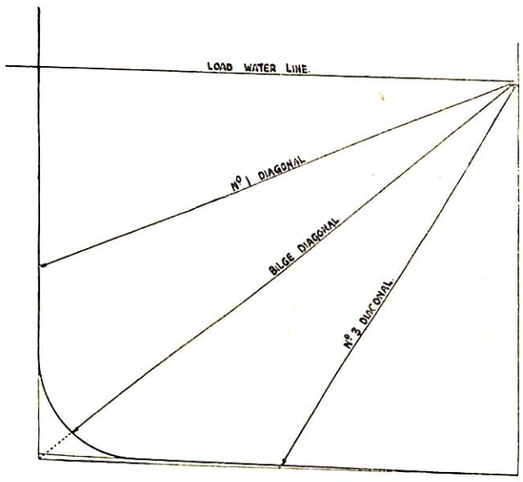
The underlying cause of the variation of resistance due to shape of section is probably to be found in the general conditions of stream line flow at the ends, so that the prismatic coefficient of the ends, combined with speed length ratio of ends and also what may be called " diagonal fineness," will influence the results. Taylor's experiments on stream line flow around vessels show conclusively that a good deal of the general flow is in a downward direction and consequently anything that can be done to make the passage as easy as possible, *i.e.* by paying some attention to the lower parts of the sections, particularly where these fair into the midship part, will probably reduce the resistance.

Level Lines and Contours.

As stated in the previous section for the average cargo vessel, the change in slope of the level lines from the load line to keel should be fairly uniform, to conform with the flow of water which is known to be along bow lines. To keep these as easy as possible for some distance transversely on each side of keel, the lowest levels should either be hollowed at their fore ends or the forefoot cut away. This has the effect of reducing the " bow breaker " and also decreases the wetted surface. At higher speeds the upper portion of the stem contour should be raked forward to lengthen the water-lines. To obtain V-sections aft some hollow at the lower levels becomes necessary. This should be kept within limits, although a little club-footing does not appear to have an adverse effect. In twin-screws where the deadwood can be cut away this hollowing can be reduced to a minimum. What must be avoided is a pronounced convex curve at the shoulder followed by a steep slope as the level line approaches the middle line, giving very steep buttocks. The levels above the aperture should be filled out and run as near to the rudder post as practical considerations will allow, to avoid eddy formation.

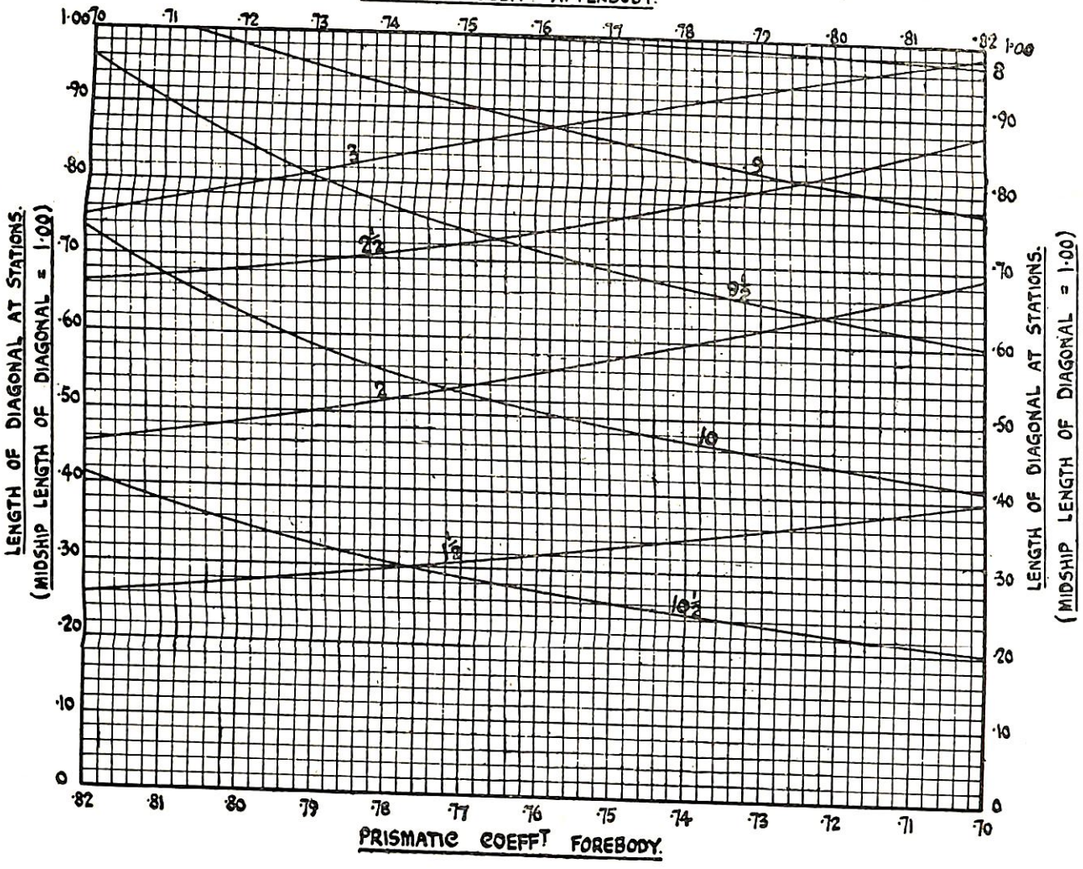
Standardised Diagram for Constructing Lines.

It will be noticed from Plate 30 that Baker has given the form of the load water-lines of his models as well as the sectional areas. Therefore, the means are at hand of constructing body plans embodying the results of these experiments.



No 1 DIAGONAL

PRISMATIC COEFFT AFTERBODY.



BILGE DIAGONAL.

PRISMATIC COEFFT AFTERBODY.

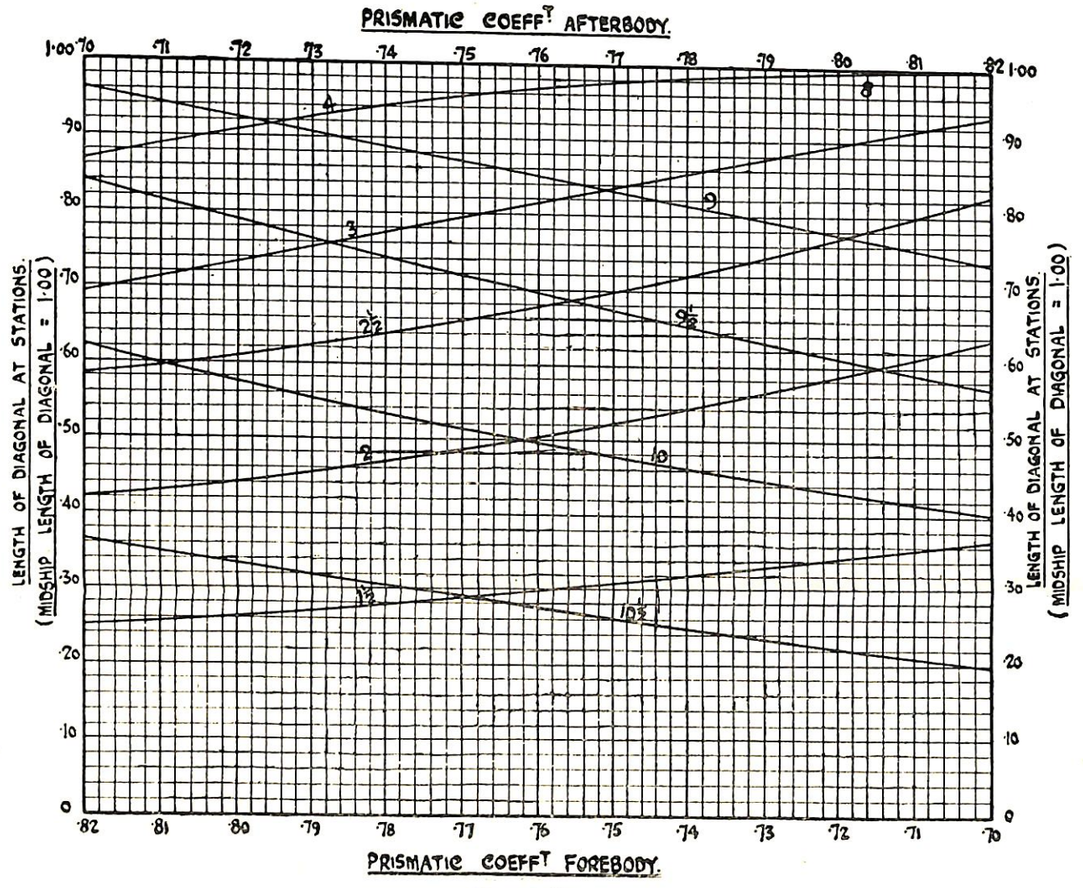
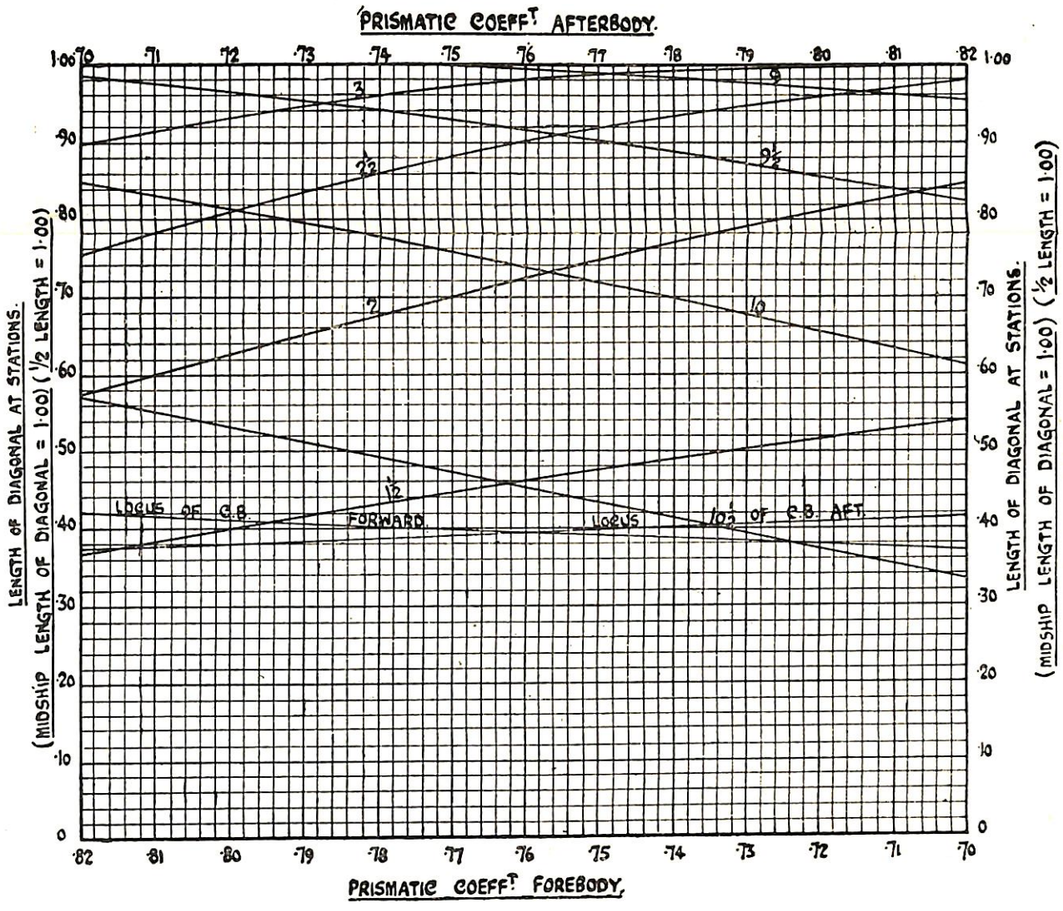
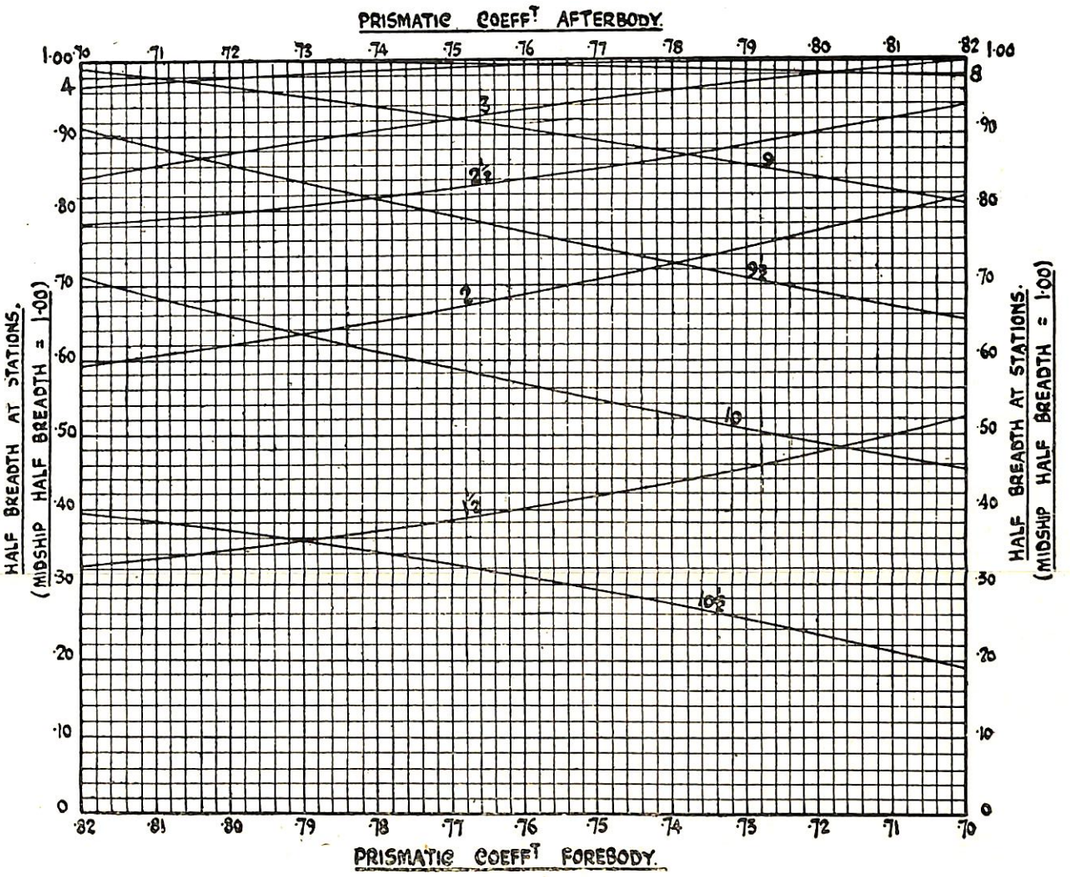


PLATE 38.

Nº 3 DIAGONAL.


PRISMATIC COEFFT AFTERBODY.
·70 ·71 ·72 ·73 ·74 ·75 ·76 ·77 ·78 ·79 ·80 ·81 ·82
1·00 ·90 ·80 ·70 ·60 ·50 ·40 ·30 ·20 ·10 0
LENGTH OF DIAGONAL AT STATIONS.
(MIDSHIP LENGTH OF DIAGONAL = 1·00) (½ LENGTH = 1·00)
3
2½
2
1½
LOCUS OF C.B. FORWARD
LOCUS OF C.B. AFT
PRISMATIC COEFFT FOREBODY.

LOAD WATER LINE.


PRISMATIC COEFFT AFTERBODY.
·70 ·71 ·72 ·73 ·74 ·75 ·76 ·77 ·78 ·79 ·80 ·81 ·82
1·00 ·90 ·80 ·70 ·60 ·50 ·40 ·30 ·20 ·10 0
HALF BREADTH AT STATIONS.
(MIDSHIP HALF BREADTH = 1·00)
4
3
2½
2
1½
PRISMATIC COEFFT FOREBODY.

The series of diagrams (Plate 38) giving coefficients for load water-line, half-draught diagonal, bilge diagonal, and quarter-width diagonal have been obtained from body plans so constructed. From them a body plan may be obtained in about 30 minutes.

To illustrate their use, suppose it is necessary to design a body plan for a ship of, say

T.S.S. 477 ft. B.P. × 62 ft. 9 in. × 28 ft. 10 in. draught.
18,800 tons displacement (bossing, say 44 tons).
Block coefficient mld. ·763.

Design midship section of, say ·983 coefficient.

Then prismatic = $\frac{\cdot 763}{\cdot 983}$ = ·776. Suppose the centre of buoyancy to be 2 ft. 3 in. aft (ex. bossing). Next obtain prismatics forward and aft respectively, as explained in Appendix B, of ·767 forward and ·785 aft. Set up lines at these coefficients on the various diagonals obtaining the corresponding proportions. Then take half B and lengths of diagonals and multiply by proportions obtained, the results being offsets for the body. It is better to use moulded displacement, making the necessary correction for shell of say 6 tons per 1000. Plate No. 39 shows the body plan thus obtained.

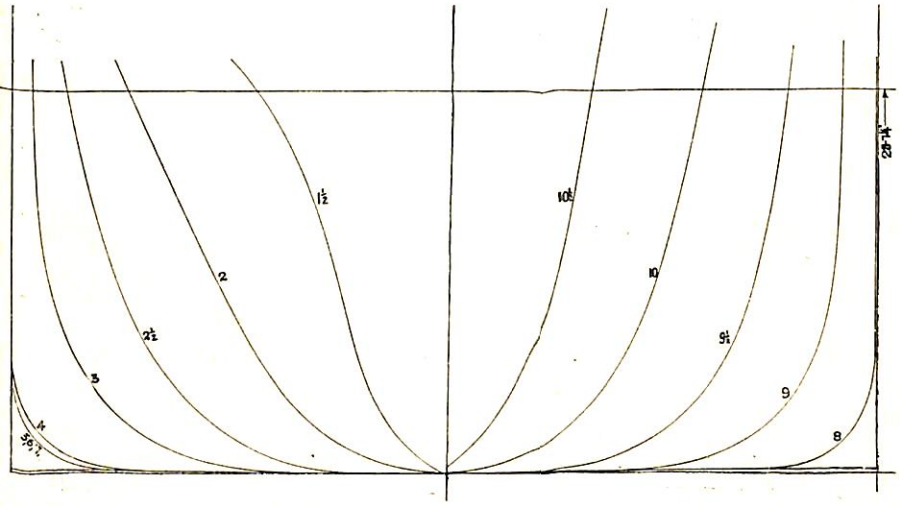


PLATE 39.

It should be noted that these results have been obtained from body plans designed for a ratio of breadth to draught of 2·25, which fairly well covers merchant practice, and length ratio of 7·65. A study, however, of Taylor's results shows :—

1. That the ratio of beam to length does not affect the resistance seriously within ordinary merchant ship limits.
2. Reduction in resistance follows increase in draught and *vice versa*.

Plate No. 40 illustrates another body plan designed in accordance with Baker's results. The dimensions taken are as follows, the coefficients being those of model 111D (see Kent's paper, 1915).

S.S., 442 ft. 6 in. BP × 58 ft. 6 in. × 28 ft. 8 in. draught.
Displacement 16,160 tons, moulded 16,037 tons, deducting shell and cruiser stern, 17 tons.
Centre of buoyancy, 2 ft. 9 in. forward amidships.
Block moulded ·763, extreme ·760, on L.W.L. ·735.
Mid area coefficient mld. ·984, extreme ·980.
Prismatic forward ·788, aft ·762. Total ·775.

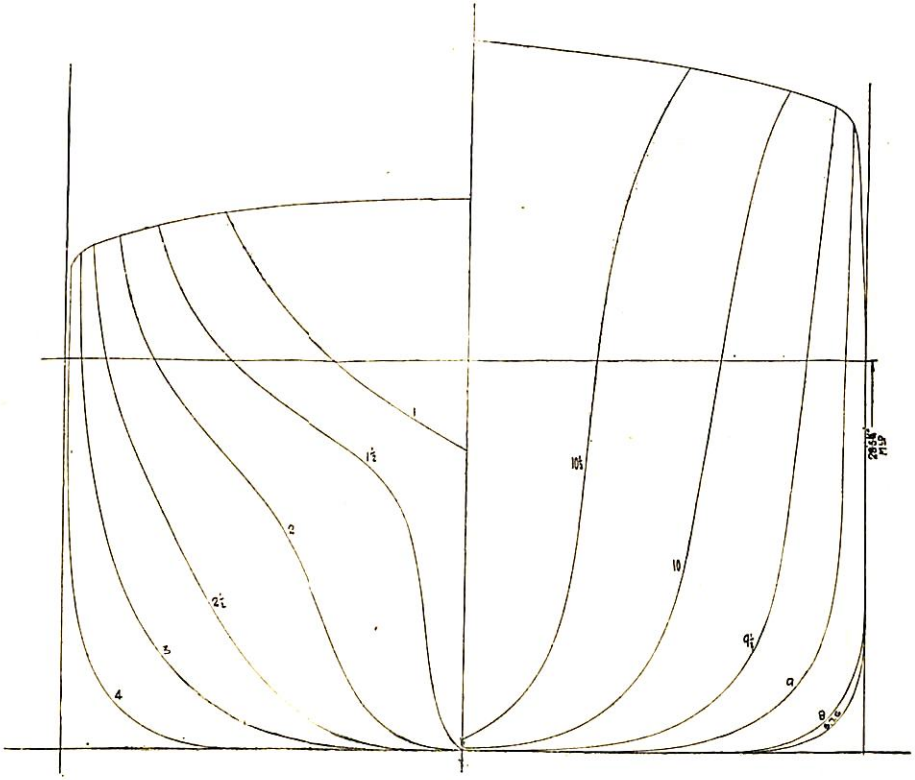


PLATE 40.

$$\frac{L}{\triangle^{\frac{1}{3}}} = 17\tfrac{1}{2}\ V = (P) \times 1{\cdot}34\ \sqrt{P \times L}$$ at $12\tfrac{3}{4}$ knots $(P) = {\cdot}514$

most suitable sea speed $12\tfrac{1}{4}$ knots at $\frac{V}{\sqrt{L}} = {\cdot}585$.

Mr. Baker's medium entrance of ·672 and run of ·638 have been used.

Plate No. 41 gives the sectional area curves and load waterlines of three very good models. The Table will show at a glance their various coefficients. Two have cruiser sterns and one ordinary.

Plate No. 42, referred to previously, gives sectional area curves for various types of ships. The diagram is self-explanatory.

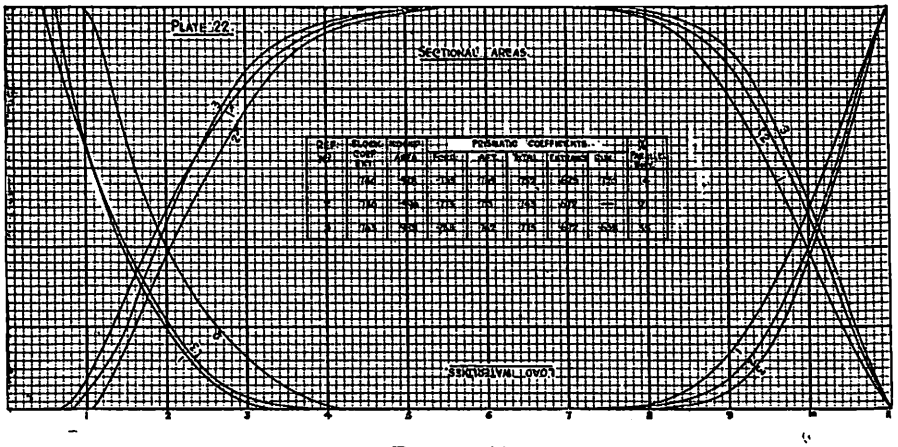


PLATE 41.

Liner Type of Curve.

It would be well at this point, before entering into a detailed discussion of the liner type, to explain the relation of Prismatic to Speed Length Ratio, a relationship which for this type is of vital importance.

Relation of Prismatic to Speed Length Ratio.

At all speeds there is a certain amount of resistance due to wave-making. At low speeds it is almost entirely due to the creation of the bow and stern diverging series, especially the bow, and almost entirely depends on the form of the ship near the ends at the waterline. The length of the ship has practically nothing to do with their creation. As the speed increases, transverse waves are

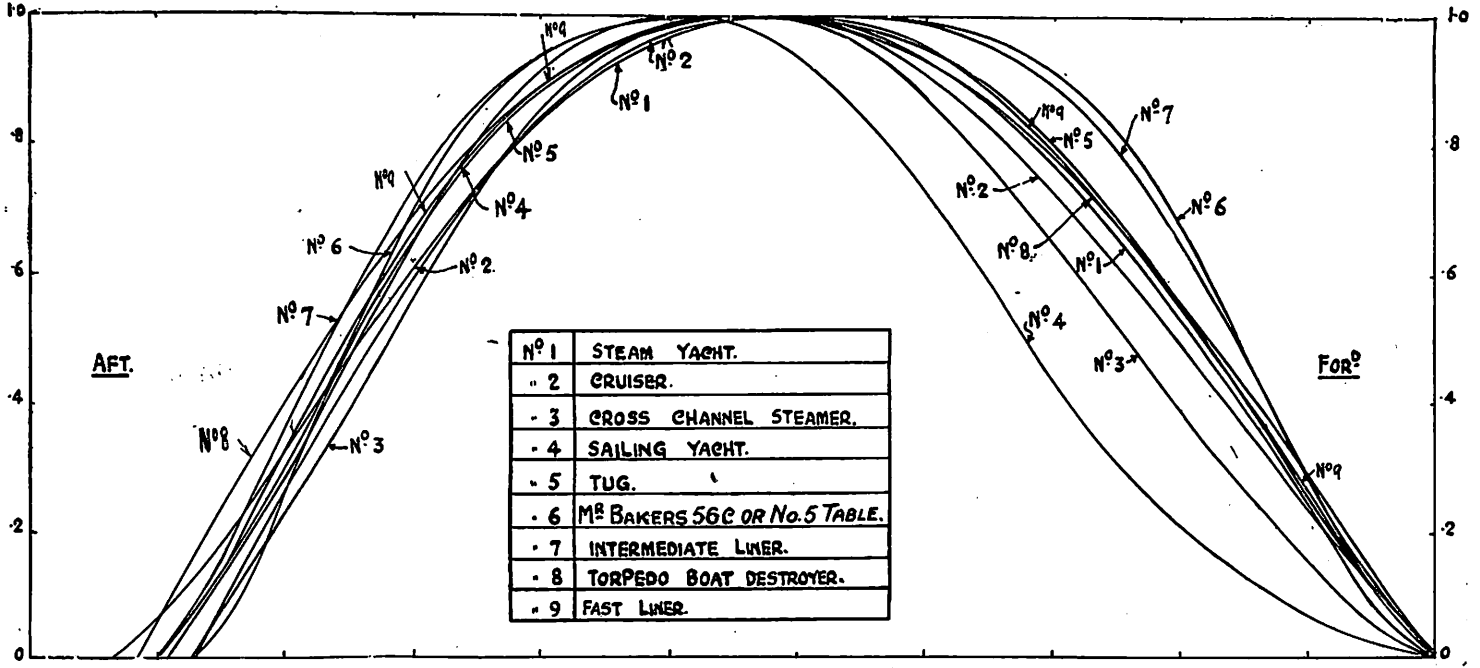
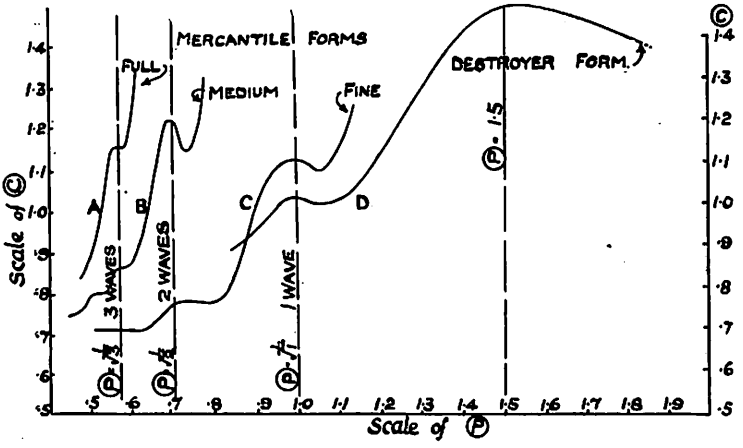

1·0
·8
·6
·4
·2
0
AFT.
FOR.
No 9
No 1
No 2
No 5
No 4
No 6
No 7
No 8
No 3
No 9
No 5
No 7
No 2
No 6
No 8
No 1
No 4
No 3
No 9
No 1 STEAM YACHT.
" 2 CRUISER.
" 3 CROSS CHANNEL STEAMER.
" 4 SAILING YACHT.
" 5 TUG.
" 6 Mr BAKERS 56C OR No.5 TABLE.
" 7 INTERMEDIATE LINER.
" 8 TORPEDO BOAT DESTROYER.
" 9 FAST LINER.

PLATE 42.

formed and become at high speeds a vital factor in resistance. Their extent has been found to depend largely on the relation of length to prismatic coefficient. In vessels such as torpedo craft forced to very high speed, form, such as relation of breadth to draft, has been found to have a vital effect on the creation of transverse waves. The Plate, No. 43, as given by Mr. Baker in his 1913



No of Curve	Prismatic Coefficient.	Percentage of Parallel Body.	Remarks.
A	·827	50	Mercantile Forms
B	·761	30	constants correct
C	·621	10·45	for 400 foot Ship.
D	·646	Nil	Destroyer. constants for 255 foot Ship.

PLATE 43.

paper, will help to explain this. It shows the results of resistance experiments on four varying types of models. The critical speeds of all the models except the destroyer one, correspond to Ⓟ = 1, $\frac{1}{\sqrt{2}}$ $\frac{1}{\sqrt{3}}$ etc., and there are flats or hollows in the resistance curve at these values. These humps are caused by the crests of the bow and stern transverse waves coinciding. At certain speeds this hump becomes very large. Mr. Baker states that the change over from this hump to the succeeding hollow has been found to occur at the natural speed of waves whose length is equal to P × L. This speed, as previously stated, is given by the formula $V = 1{\cdot}34\sqrt{P \times L}$. The speed at which the other and smaller humps occur

can be found by substituting $\frac{L}{n}$ for L, n taking account of the number of wave lengths between the two systems. A study of Plate No. 43 will give the (P) values, which are likely to be troublesome at different prismatics and correspondingly those that are beneficial.

Hollows are found to occur at (P) values of

$$\sqrt{\frac{4}{3}} \quad \sqrt{\frac{4}{7}} \quad \sqrt{\frac{4}{11}} \quad \sqrt{\frac{4}{15}} \quad \sqrt{\frac{4}{19}} \quad \text{and so on.}$$

To take an example, suppose we wish to find lengths for a ship of 13 knots speed and ·775 prismatic at

$$(P) = \sqrt{\frac{4}{15}} \text{ we get } \sqrt{\frac{4}{15}} = \cdot 746 \frac{13}{\sqrt{\cdot 775 \times L}}$$

giving L = 455 ft., or we could have the length and prismatic fixed and find the speed. These results Mr. Kent, as we have already stated, has embodied in Plate No. 23. A very interesting series of articles in " Marine Age and Shipping Record " has recently been published by Mr. F. McAllister, discussing this question of humps and hollows, giving formulae for their prediction.

Area Curve for Liners.

For the intermediate liner of about 16-17 knots and the high-speed liner, the information published is not so extensive as that on the cargo vessel. However, from Sadler's papers and Baker's finer series, information and guidance can be obtained. In Baker's 1914 paper there is one model of exceptionally low (C) value, viz., No. 5, group F. This model had an entrance of ·625 and run of ·638, with 10·45 per cent. of parallel body, total prismatic ·670, block ·656, mid-area ·980. Its highest economical value was about ·67 at 16 knots for a 400 foot vessel. The sectional area curve is given in Plate 42. Its features are a medium hollow forward in sectional area curve and a straight run aft. A body plan constructed from this curve would give very U-sections forward and V-sections aft, both suitable for easy propulsion, but in actual practice it would be difficult to obtain the necessary stability owing to the very fine water-line. However, its main features can be followed and a very economical ship obtained.

Professor Sadler in 1907 and 1908 delivered to the American Society of Naval Architects two papers which contain most valuable data on this type. His F6 series deal with the intermediate liner

type of $\frac{V}{\sqrt{L}}$ ·75 to ·90, and his F7 series with the transatlantic intermediate type of merchant vessel $\frac{V}{\sqrt{L}}$ ·60 to ·75, with a limiting economical speed of about ·725. Dealing with the F6 series first, Plate 44 will illustrate the type of sectional area curve used. There are two types of bow and two types of stern used, viz., fine bow, full bow, fine stern and full stern. These were tried in four different ways, viz., fine bow fine stern, full bow fine stern, full bow full stern, fine bow full stern.

In his F6 (1), with fine ends, there was about 20 per cent. parallel body and with full ends (round lines) no parallel body.

In this series F6 (1) a form with fine waterline is best, not too full at bilge diagonal forward. For the aft body, the curve of sectional areas should taper gradually from mid-section somewhat full on waterline, with an easy bilge diagonal. F6 (1) the minimum residuary resistance is with about 10 per cent. parallel body. Curve of areas slightly hollow forward and fore body waterline slightly hollow sections U'd. A finer model would have no parallel body area curve hollow both ends, fore sections V'd fore body waterline straight if $\frac{V}{\sqrt{L}} > 1{\cdot}2$.

F6 (2) and (3) had same sectional area curve as F6 (1) but greater beam, F6 (3) having a finer prismatic than (2), as shown in Table 13. By increasing the beam, the parallel body was reduced. These changes gave a more easily driven vessel than F6 (1), F6 (3) having the least resistance. 400 ft. vessels, corresponding to F6 (1) and (3) would have the following comparative dimensions, viz.,

F6 (1)—400 ft. × 50 ft. × 23 ft. 4 in. × 8710 tons displacement.
F6 (3)—400 ft. × 55 ft. × 23 ft. 4 in. × 8710 ,, ,,

Plate No. 44 illustrates the type of sectional area curve for the F7 series. Length/beam = 8 service speed, $\frac{V}{\sqrt{L}}$ = ·60 to ·75 limit of economical speed ·725.

Four different types were tried, as in F6, and the Table 14 gives the results for the best ends.

From the above Table it will be seen that it is advantageous to have a comparatively long parallel body and fine bow in the fore body, while with the after body the best results seem to be obtained by adopting a form with a more gradual diminution of area from the midship section aft.

The vast majority of passenger liners range from about ·6 to ·7 block, ·65 probably including most of them, the finest probably

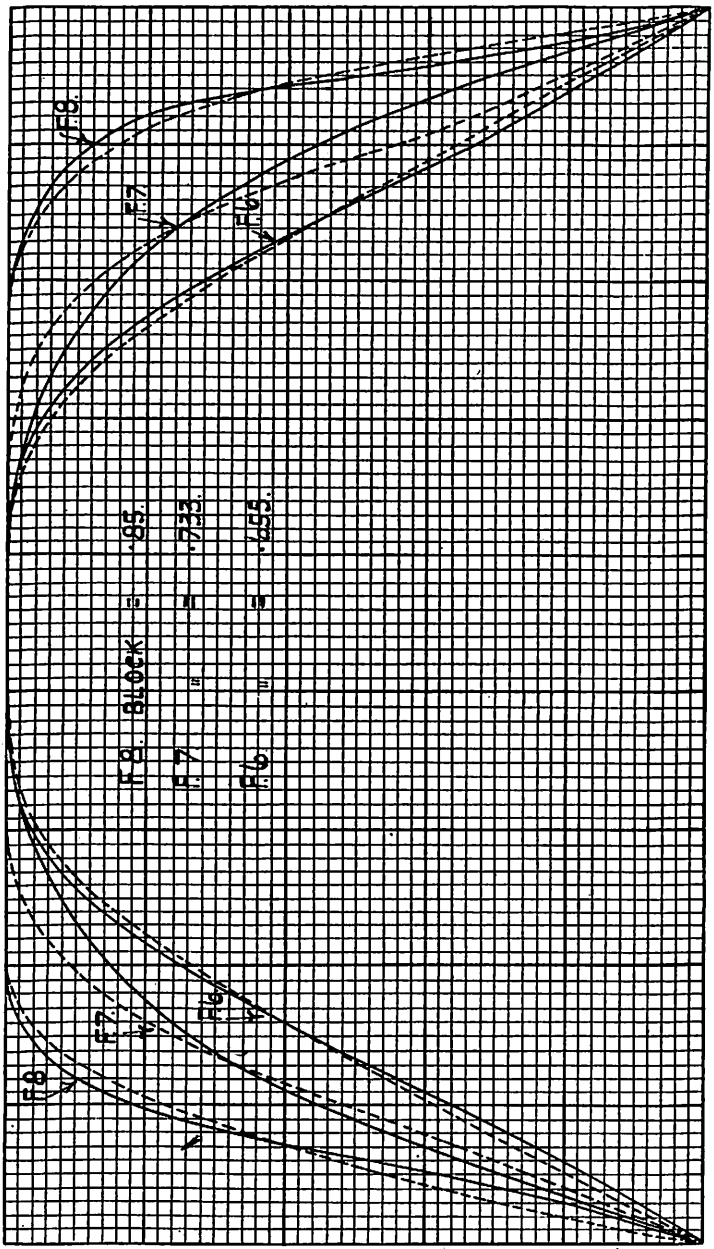


PLATE 44.

Table 13.

	Length / Beam	Beam / Draught	Length / Draught	Coefficients. Block	Prismatic	Mid-Area.	Best Ends	Residuary Resistance per ton for various $\frac{V}{\sqrt{L}}$ ·45	·50	·55	·60	·65	·70	·75	·80	·85	·90	·925
F6 (1)	8	2·142	17·142	·653	·678	·964	Fine Bow Fine Stern			1·0	1·28	1·58	1·85	2·08	2·45	3·75	5·19	7·0
F6 (2)	7·272	2·358	17·142	·594	·678	·874	,,			1·0	1·24	1·49	1·76	2·07	2·43	3·08	4·76	6·4
F6 (3)	7·272	2·358	17·142	·594	·664	·895	,,		·70		1·16	1·40	1·69	2·05	2·4	3·0	4·2	5·3

Table 14.

	Beam / Draft	Length / Draft	Coefficients. Block	Prismatic	Mid-Area.	Best Ends.	Res. Resistance in lbs. per ton displacement for various speeds $\frac{V}{\sqrt{L}}$ ·45	·50	·55	·60	·65	·70	·75	·80	·85	·90	·95
F7 (5)	3·0	24	·697	·734	·950	Fine Bow Full Stern	·83	1·0	1·25	1·48	1·74	2·025	2·57	4·76	6·26	8·58	13·95
F7 (6)	2·5	20	·715	·747	·956	Fine Bow Full Stern	·75	·96	1·13	1·37	1·61	1·875	2·70	5·05	7·0	8·81	...
F7 (7)	2·143	17·143	·733	·760	·964	Fine Bow Full Stern	·75	·97	1·18	1·41	1·65	2·03	2·85	5·54	7·75	...	...

The water-line coefficients were as follows :—

	Fine Ends.	Full Ends.
F 5	·795	·807
F 6	·830	·812
F 7	·852	·829

being the Mauretania of ·59 block, a fineness made possible by her great beam, which also allowed U sections forward with slightly hollow sectional area curve, which was found to be the ideal form when dealing with F6 series. A typical sectional area curve for liner of about 20 knots is given in Plate 42.

The Influence of the Bulbous Bow on Resistance.

This type of bow has been fitted for a very long period to all warships in both the British and American navies and has been found to be less resistful than the ordinary bow.

The reason for this is because the bulbous or ram bow is an extreme case of an U bow, being much fuller below the waterline than at the waterline. The excess pressures set up round the ram being well below the surface are more absorbed in pumping the water aft where it is needed and less absorbed in raising the surface and producing waves than if the same displacement were brought close to the surface.

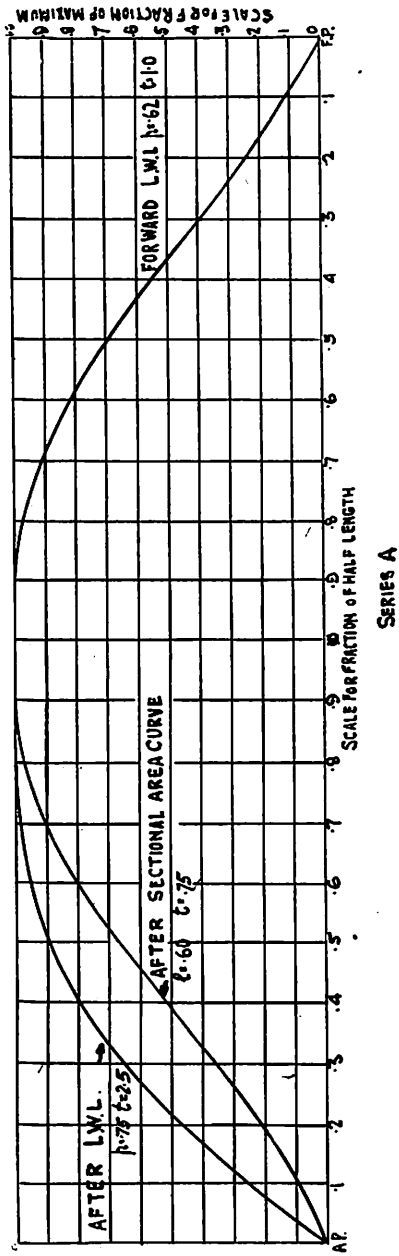
Recently the Clyde Line of New York have fitted this bow on their liners with considerable success. In 1923, Admiral Taylor carried out a series of experiments on this type of bow. These experiments not only show the effect of the ram bow on resistance, but what an important factor the bow slope of the curves of sectional areas is in this respect. This slope is expressed by a quantity t obtained as follows—for the normal form where the ordinate of the sectional area curve is zero at the F.P., draw the tangent at the bow to the curve of sectional areas. This will cut the vertical at the centre of length intercepting on it a certain ordinate. Then t is the ratio between this ordinate and the ordinate of the sectional area curve at the centre of length.

The ram bow is expressed quantitatively as follows :—The sectional area curve instead of coaming to zero at the F.P. has an ordinate there, representing the area at the F.P., and the extent of this bulbousness is expressed by the ratio between this F.P. area and the area of the mid-section. The symbol f is used to designate this ratio. When f has a value it is necessary in order to determine t correctly to deduct f from both the midship ordinate of the tangent at the bow and the midship ordinate of the curve of sectional areas and then proceed as before.

Two series of models called A and B, of about 20 sets in each were tested. Plates 45, 46 and 47 show the sectional area curves for each set with the corresponding t and f values. Table 15 gives the characteristics of these models expanded to a 400 foot ship :—

The wetted surface varied with t and f.

Models A are suitable for the fast passenger vessel or battle cruiser type, whilst B are of the battleship type.


SCALE FOR FRACTION OF MAXIMUM
AFTER L.W.L.
h·78 t·2.5
AFTER SECTIONAL AREA CURVE
C·60 C·75
FORWARD L.W.L h·62 t·1·0
A.P.
F.P.
SCALE FOR FRACTION OF HALF LENGTH
SERIES A

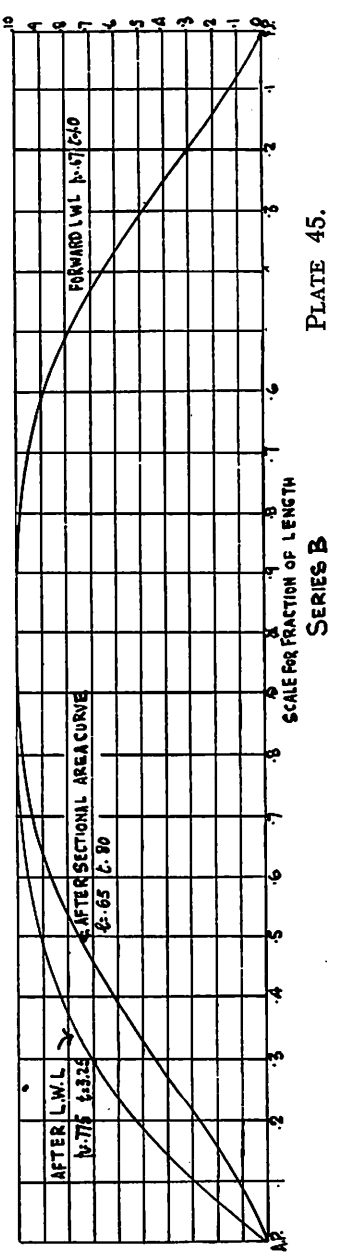

AFTER L.W.L
h·78 t·3.25
AFTER SECTIONAL AREA CURVE
C·65 C·90
FORWARD L.W.L h·67 t·1·0
A.P.
F.P.
SCALE FOR FRACTION OF LENGTH
SERIES B

PLATE 45.

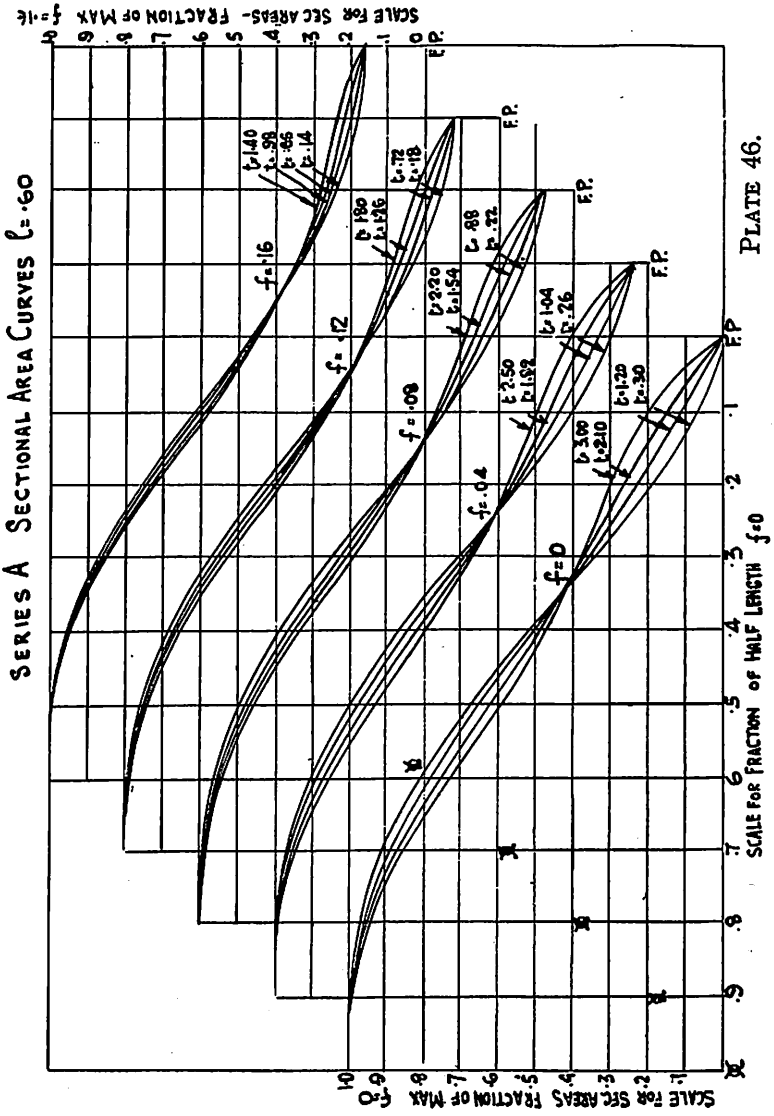

SERIES A SECTIONAL AREA CURVES l=·60
SCALE FOR SEC. AREAS FRACTION OF MAX. f=0
SCALE FOR SEC AREAS- FRACTION OF MAX f=·16
SCALE FOR FRACTION of HALF LENGTH f=0
f=·16
f=·12
f=·08
f=·04
f=0
E.P.
b 1·40 t··98
b ·86 t·14
b 1·80 t·1·26
b ·72 t··18
b 2·20 t·1·54
b ·88 t··22
b 2·50 t·1·92
b 1·04 t··26
b 3·00 t·2·10
b 1·20 t··30

PLATE 46.

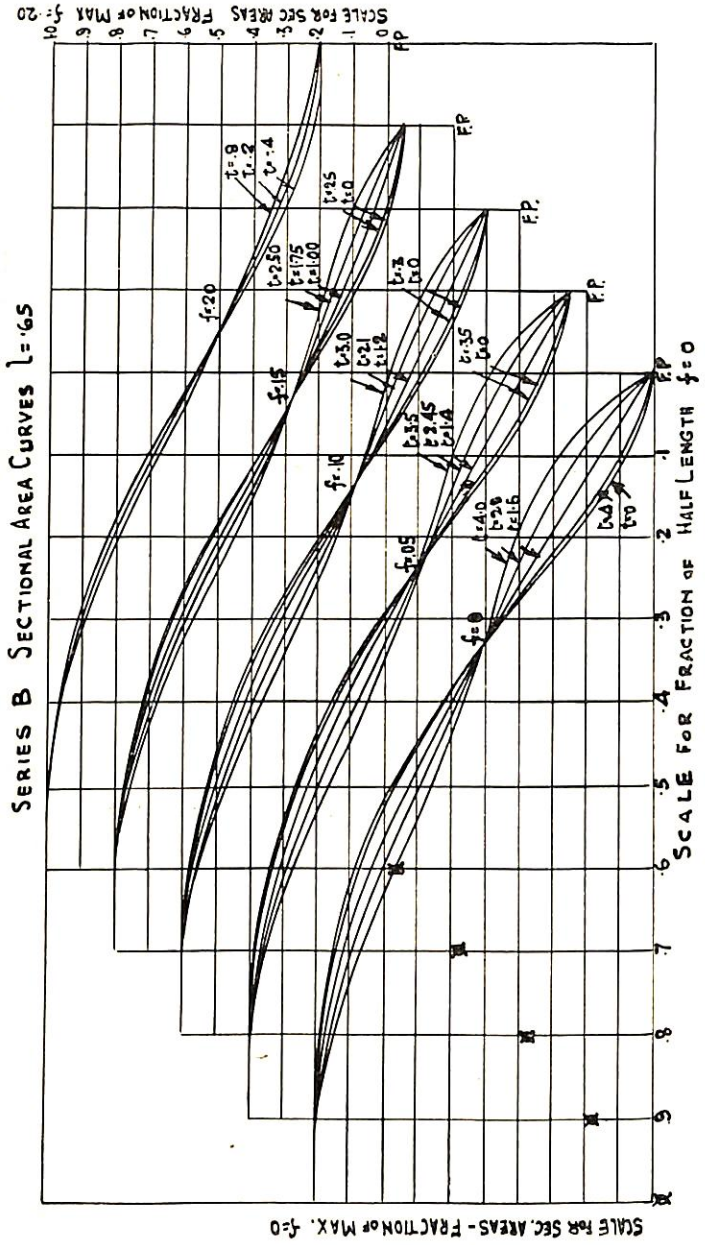

SERIES B SECTIONAL AREA CURVES L=1.65
SCALE FOR FRACTION OF HALF LENGTH f=0
SCALE FOR SEC. AREAS - FRACTION OF MAX. f=0
SCALE FOR SEC AREAS FRACTION OF MAX f=.20
A.P.
F.P.
f=.20
f=.15
f=.10
f=.05
f=0
τ=.9
τ=.8
τ=.4
τ=2.50
τ=1.75
τ=1.00
τ=.25
τ=0
τ=.3
τ=0
τ=3.0
τ=.21
τ=.12
τ=.35
τ=0
τ=3.5
τ=2.45
τ=1.4
τ=0
τ=4.0
τ=2.8
τ=1.6
τ=0

PLATE 47.

TABLE 15.

	A.	B.
Length, ...	400 ft.	400 ft.
Breadth, ...	45·66	64·64
Draft, ...	13·62	20·20
Prismatic Coefficient, ...	·60	·65
M. Section Coefficient, ...	·92	·99
Displacement Length Ratio,	60	150
Beam to Draft Ratio, ...	3·35	3·20
Coeff. L.W.L. forward, ...	·62	·67
,, ,, aft, ...	·75	·775
Block Coefficient, ...	·552	·6435
Displacement, ...	3840 tons.	9600 tons.

Plates 48 and 49 summarise the results of these tests for both series by means of four curves, showing values of f and t and the percentage of total resistance saved through the use of the bulbous

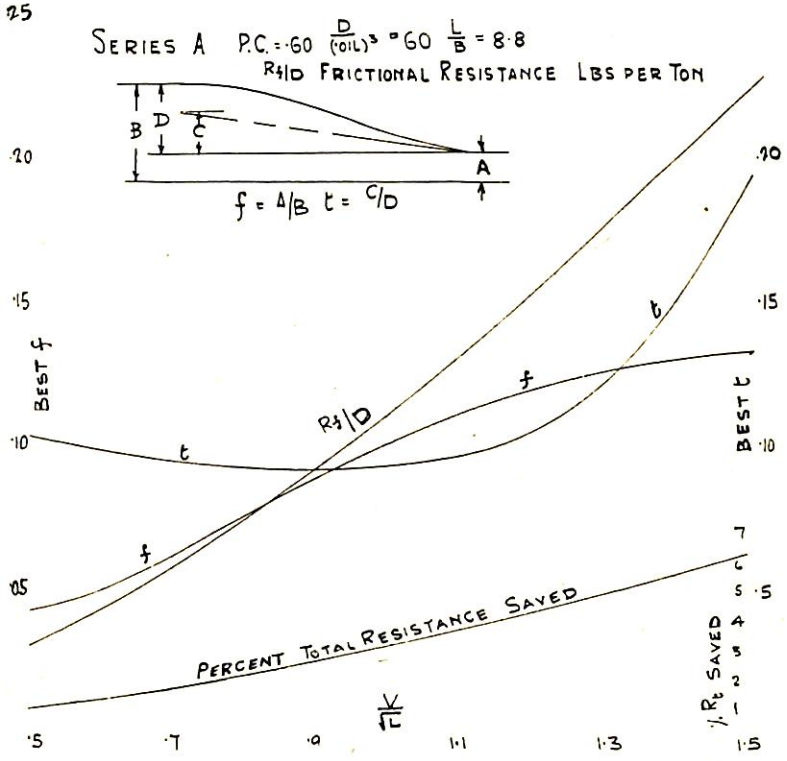


PLATE 48.

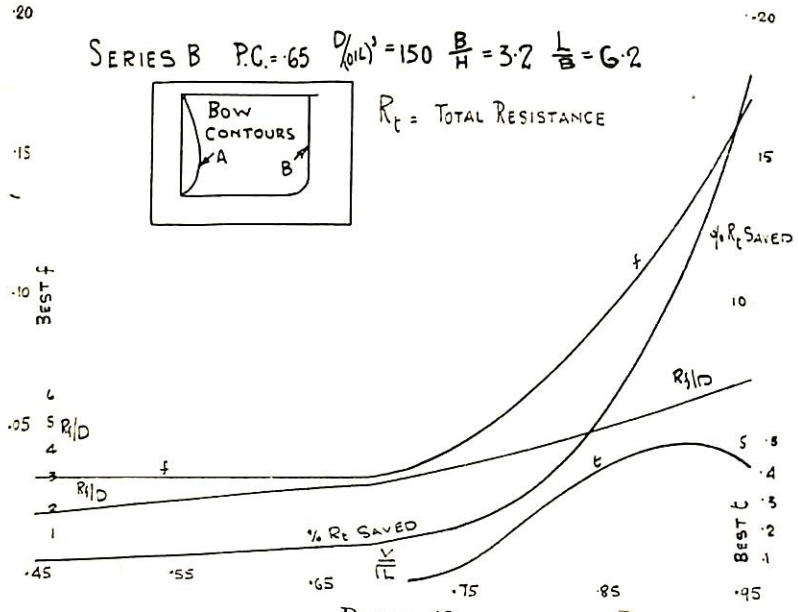


PLATE 49.

forefoot at different speeds up to a speed length ratio of 1·5. The frictional resistance expressed in lbs. per ton of displacement is also shown. Taylor expresses this in the form of contour curves which the student can obtain in the original paper. A study of diagram 49 will show that the saving in resistance is very important in the B type at speed length ratios over ·7, and the values of f also become large. Although the extreme bulbous forefoot can hardly be applied to the usual type of merchant vessel, considerable advantage can be obtained in using it in a modified form by reducing f to 0 and using a curve with the proper values of t. Plate 50 gives these values for various displacement length ratios.

Summing up Series A, a properly chosen bulbous bow will save something like 10% residuary resistance and from 1% to 3% total for speeds up to $\frac{V}{\sqrt{L}} = 1$; at higher speeds the relative saving is less and disappears at speeds as high as $\frac{V}{\sqrt{L}} = 1{\cdot}5$. As regards t the best value remains close to unity until we reach $\frac{V}{\sqrt{L}} = 1$. It then increases rapidly with $\frac{V}{\sqrt{L}}$ until it reaches 3, when $\frac{V}{\sqrt{L}} = 1{\cdot}25$ and still more for higher values.

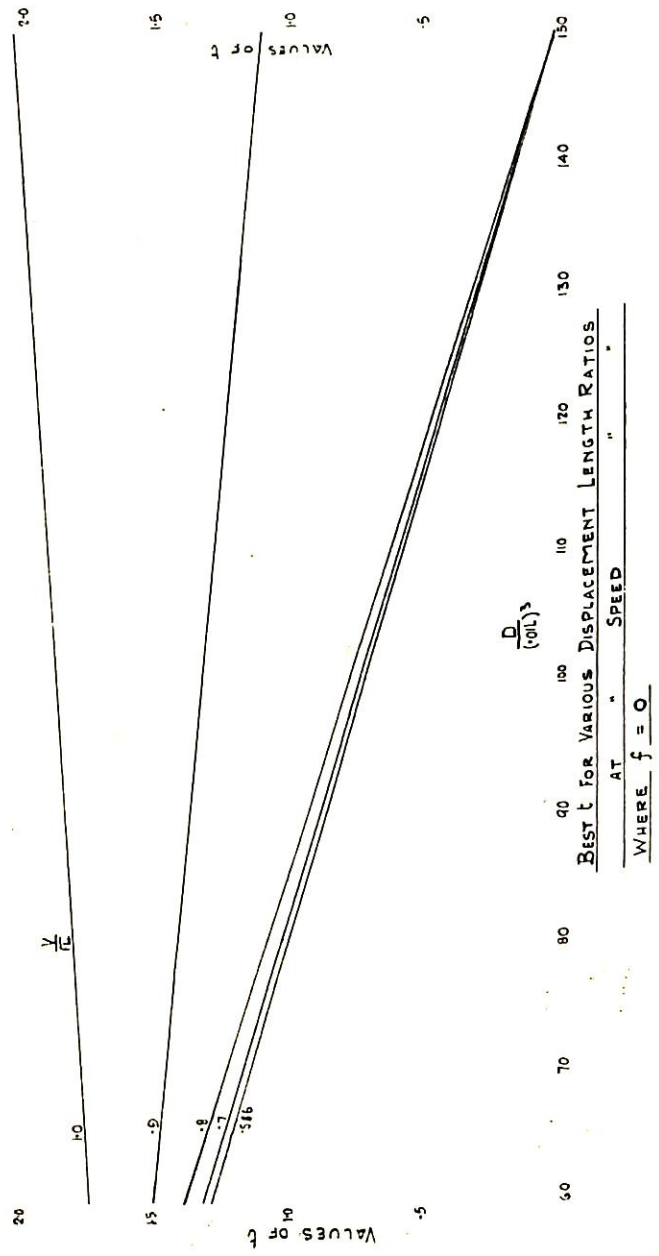

Values of t
Values of t
V/√L
D/(.01L)³
Best t for Various Displacement Length Ratios
at " Speed
Where f = 0

PLATE 50.

Series B.—Rather full moderate speed vessels. At low and moderate speeds, the best value of l is about zero, which is quite in accordance with tests of moderate speed vessels.

For high speeds large prismatic coefficients are needed associated with full ends and for low and moderate speeds small prismatics with fine ends.

How this type of bow would behave in a seaway, especially at low drafts, is a question which should be considered before fitting it to such a vessel.

The Effect of Appendages on Resistance and Propulsion.

Before entering into a detailed explanation of Luke's and Kempf's experiments on this important subject, it will be necessary to explain what is meant by the frictional wake.

The friction of the water on the surface of the vessel causes a surrounding belt of water to follow in the direction of the vessel's motion and its forward velocity gradually increases as we go aft. Thus at the stern we have a considerable belt of water having a forward velocity. This velocity varies in amount and direction, being greatest at the surface and very little at the keel. It can be assumed in the case of the propeller to have a certain uniform velocity forward. We call this body of moving water the frictional wake and its speed is usually expressed as a fraction of the speed of the ship, say xV. Its speed is greater nearer the middle line of the vessel and consequently will have more influence on single-screw ships than on twin. There is another wake known as the stream line wake, which is of lesser extent. This explanation will show the importance of this wake, as the propeller has thus to work in water which has this forward velocity. Consequently the speed of the propeller *through the water* is not the speed of the ship, but $V-xV=V_1$ say. We can thus see that the propeller will derive an increase of thrust from this source, especially in single-screw ships. However, this frictional wake is complicated by the existence of other factors.

(*a*) The stream line wake already mentioned (the stream lines closing round a vessel tend to a diminution of velocity and increase of pressure) ; especially is this so with full-lined vessels, as we have already stated in other sections.

(*b*) The presence at the stern of the vessel of a wave ; especially is this so at high speeds, the particles forming the wave having an orbital motion. At a crest this orbital motion is forward, *i.e.* same as the ship, in a trough they move aft. Thus a screw working under a crest will have a large forward wake, but if near a hollow the effect will be to cancel the frictional belt and stream line effect and give even a negative wake. Destroyers travelling at high

speeds usually have the stern in a small hollow and exhibit this phenomenon. Their wake is seldom more than 2% positive. The presence of the propeller itself causes an interference with the natural closing in of the stream lines at the stern, thus causing an increase of resistance greater, naturally, in single-screw vessels than in twin.

The usual practice is to regard this increase of resistance as a loss of thrust of the propeller. Suppose T to represent the thrust required to overcome the ship's resistance + this increase and R the thrust to overcome the resistance alone, then T—R is referred to as the thrust deduction and $T-R=t\,T$, so that $R=T\,(1-t)$ and $1-t$ is called the thrust deduction factor and is usually considered to balance the wake gain factor $1-x$ or $\frac{1-t}{1-x} = 1$.

In twin-screw vessels the bossing is another factor tending to interfere with the stream line flow and consequently increasing resistance. The angle this bossing has to the horizontal has a very pronounced bearing on this point. Mr. Luke of Clydebank carried out a series of very interesting experiments on this subject and recently Prof. Bragg, in the States, has made a notable contribution.

In Luke's 1910 paper, reference is made to experiments on models with bossings and to their influence on screw propeller performance. He experimented with 5 sets of bossings at angles of 0°, 22½°, 45°, 67½° and 90° from horizontal (see Plate 51). These bossings were made uniform, as it was desired to find the effect of the angle, not the slope. From Plate 51 it will be seen that the resistances at 0° and 90° are greatly in excess of the other bossings, naked hull resistance being unity. Luke then investigated the hull efficiency elements and found that with horizontal bossings and propellers turning outwards a large wake results, which decreases steadily with increase of slope. With propellers turning inwards, the effect is the reverse. This looked as a gain, but Luke found on further investigation that the increase in hull resistance, due to the presence of the bossings, just about balanced the gain from the wake, so that the net propulsive gain was nil. The most important discovery, however, was that while high wake values accompanied horizontal bossings with outward turning screws, a very low wake was associated with inward turning screws with the same horizontal bossings. Where no bossings are fitted, direction of rotation of screw seems immaterial, but it is very essential to adopt outward turning when bossings of less than 45° slope to the horizontal are fitted. Ignoring screw efficiency, these results lead to the conclusion that inward turning screws require an angle of about 45° and outward turning do best with smaller angles than 45°. If the screw efficiency be taken into account, horizontal bossings and outward turning screws or vertical bossings and inward turning

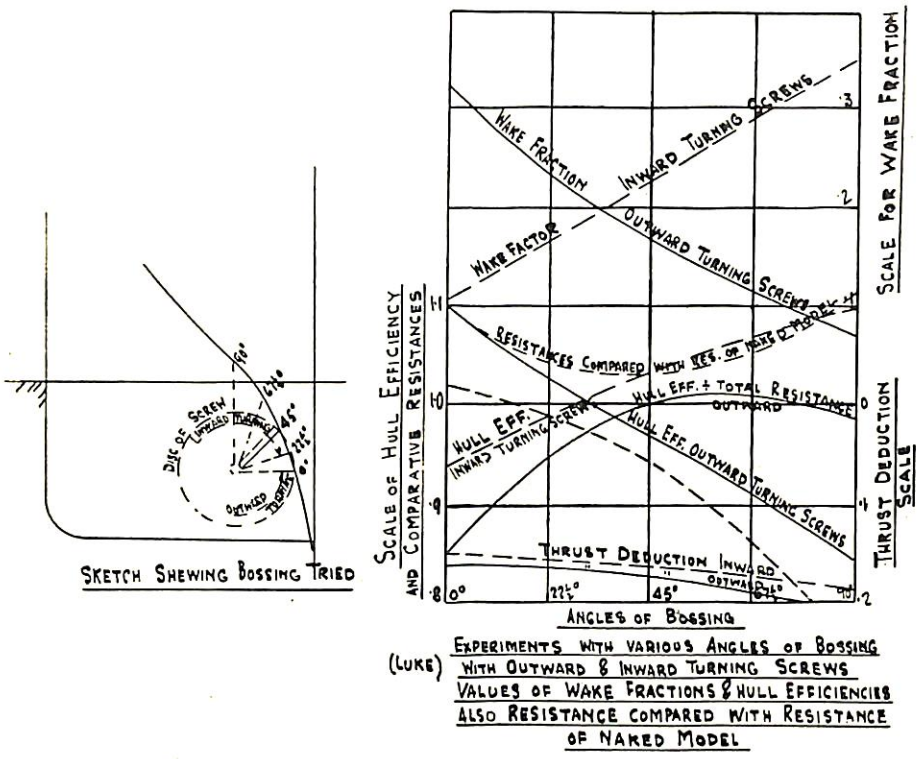

SKETCH SHEWING BOSSING TRIED
WAKE FRICTION
INWARD TURNING SCREWS
OUTWARD TURNING SCREWS
WAKE FACTOR
RESISTANCES COMPARED WITH EFF. OF HULL & TOTAL RESISTANCE
HULL EFF. + TOTAL RESISTANCE OUTWARD
HULL EFF. INWARD TURNING SCREW
HULL EFF. OUTWARD TURNING SCREWS
THRUST DEDUCTION INWARD
OUTWARD
SCALE OF HULL EFFICIENCY AND COMPARATIVE RESISTANCES
SCALE FOR WAKE FRACTION
THRUST DEDUCTION SCALE
ANGLES OF BOSSING
0°
22½°
45°
90°
(LUKE) EXPERIMENTS WITH VARIOUS ANGLES OF BOSSING WITH OUTWARD & INWARD TURNING SCREWS VALUES OF WAKE FRACTIONS & HULL EFFICIENCIES ALSO RESISTANCE COMPARED WITH RESISTANCE OF NAKED MODEL

PLATE 51.

screws give a high wake value, which means a high slip and low efficiency of screw or large diameter with smaller pitch and large bossings, the screw efficiency dropping, but not so much as in the former case. This loss just about balances the gain in hull efficiency (comparing horizontal with 45° bossing) where hull efficiency $= \frac{1-t}{1-x}$. It can be safely concluded that either inward turning combined with horizontal bossings, or outward with vertical, will result in a bad performance.

It may be stated here that the fore body has practically no effect on the wake.*

Mr. Luke's experiments dealt mainly with the effect of the slope of the bossing on the wake ; they did not take into account how this latter might be affected by the shape of the after sections. However, Dr. Kempf, in Germany, has published a notable paper dealing with

* This statement has recently been controverted by Prof. Bragg.

this phenomenon. Until recently all experiments have been conducted with naked towed models and detached propellers. McEntee, as has already been stated, being the first to make use of the inside drive, thus opening up new possibilities for more accurate deter-

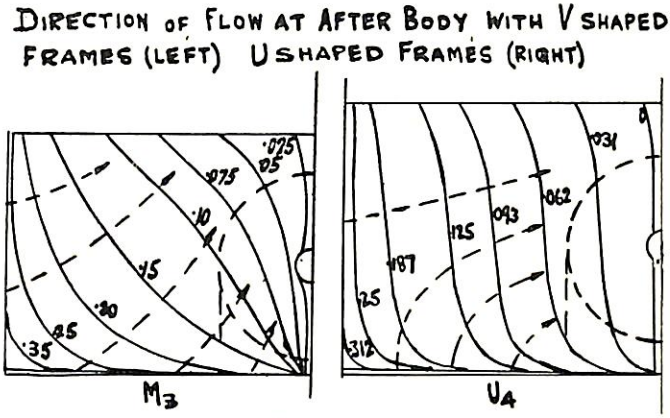


PLATE 52.

mination of the delicate and fluctuating relations between the ship form, propeller, rudder, etc. His paper dealt with the fineness of the after end, not with the shape of the sections. Kempf, however, has taken up this question and his results are exceedingly interesting and useful. Plate 52 indicates the form of sections experimented with for a ship of about ·768 block. The arrows indicate the direction of the stream line flow round the stern of the vessel. In the case of U frames, the water flows more horizontally towards the

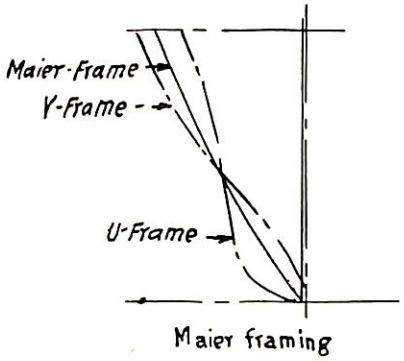


PLATE 53.

propeller and is more evenly distributed over the disk. With V frames, on the contrary, the flow to the upper blades is interfered with considerably. It is easily seen from this that a single screw vessel with V frames at a low draft will show a considerable amount of suction and poor efficiency. As shown on Plate 52, the U form creates an inboard flow and V an outboard flow, both absorbing energy. From this it may be inferred that an intermediate form, such as what is known in Germany as the Maier frame, shown in Plate 53, will absorb the least energy. Several ideas of utilising this flow by diverting it into a direction opposite to the rotation of the screw to regain tangential losses and increase propulsive efficiency have recently been evolved in Germany, such as that of Dr. Hass, which is to regain the losses forward of the propeller and that of Dr. Wagner to regain the losses abaft by means of stationary guide vanes or what is known as the contra-propeller.

The Relation between Spectacle Framing and Ship Form.

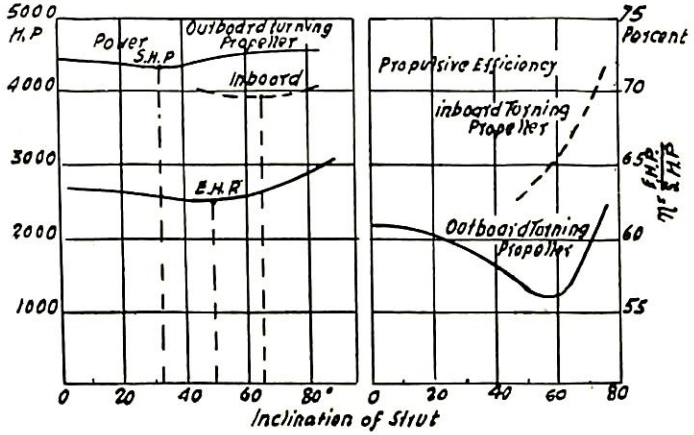
For twin-screw ships, U framing is preferable at low speeds, the inclination of the struts not being over 15° with outboard turning propellers to utilise the inboard flow created by the ship form and spectacle framing.

Dr. Kempf gives the three following alternatives for the position and design of the spectacle framing :—

(1) The bossing and framing located as parallel to stream lines as possible, and inclined 45°. This arrangement gives minimum resistance and practically no diverting of flow takes place. The propulsive efficiency is therefore the same whether inboard or outboard turning propellers are used. This is in accord with Luke as regards the inward turning, but not quite so as regards the outward turning for, as has already been stated, the angle should be smaller than 45°.

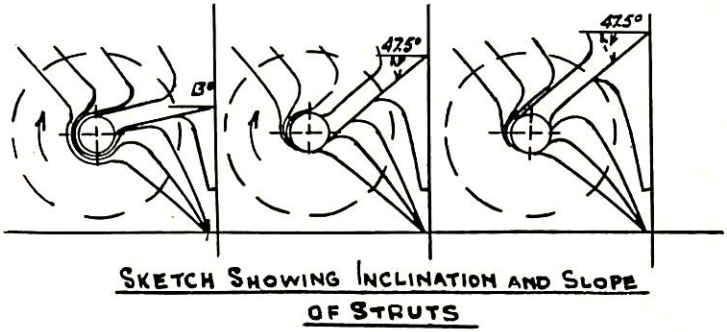
(2) The spectacle framing located more horizontal, the resistance increases some, an inboard flow being created ; but the outboard propeller will utilise this flow. Up to date it has not been proved whether V frames are more effective in connection with horizontal or inclined bossing. It has been established, however, that U frames in connection with horizontal bossing are more efficient.

(3) Bossing inclined greater than 45° increases the outboard flow created by the ship's form. This requires inboard turning screws to utilise the deflection ; V framing in this connection gives the best propulsive efficiency, but the design interferes with the manoeuvring capacity.



Result of test with twin screw model having U shaped after body framing

PLATE 54.



SKETCH SHOWING INCLINATION AND SLOPE OF STRUTS

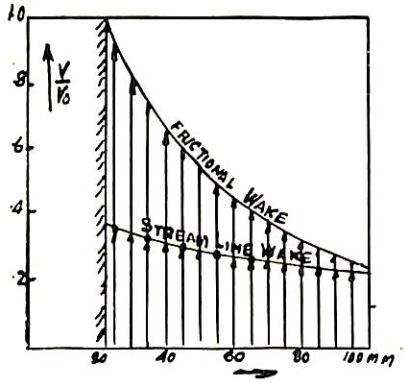
PLATE 55.

Plate 54 gives the results in the form of curves and Plate 55 the general outline of the framing employed. The inclination of the struts, as well as their slope, is of great importance. They must be designed to give sufficient deflection to minimise the tangential losses in the propeller jet. Some improvement in this respect can be obtained by fitting guide vanes to the struts. As regards single-screw ships, the flow action forward of the screw can be utilised only by (1) a body post of unsymmetrical section fairing into the lines; (2) specially designed guide vanes attached to the ordinary port.

The Contra-propeller Company have developed this idea with considerable success, especially is this so with tow-boats where the load on the propeller is great.

The tangential losses of the screw amount theoretically to 7%, which represents the maximum gain for guide vanes forward. In most cases more than 7% has been realised ; the addition is due to reduction of a previously existing resistance caused by eddy formation aft of the body post.

Prof. Kempf makes the following interesting remarks in connection with the wake :—" It consists, as we have seen, of two separate units, namely a streamline wake caused by potential flow and a frictional wake caused by drag on surrounding flow." Plate 56 shows measurements of these wakes. The more frictional wake covered by the propeller disk, the greater the utilisation of the same.



Wake behind single screw model

PLATE 56.

When designing the after end, it is therefore very important to guide the wake as concentrated as possible to the propeller disk. The ship form, in order to create the least possible suction, should be as far from the screw as possible. In a quite recent paper, Admiral Taylor tested this out. He tried three different sized propellers in six different positions, fore and aft and vertically. The results indicated that the smaller propeller was the most efficient when located as high as possible and reasonably close to the body post.

With the present twin-screw ship form, it is impossible to utilise the wake to any great extent.

Ship's Form Aft of Propeller.

Mention has already been made of the contra-propeller or stationary guide vanes for deflecting the propeller jet to regain tangential losses. Savings in this respect are said to amount to 12% in some cases.

These contra-propellers have different numbers of blades—6, 4 and 2. The six-bladed are the most efficient, but smaller numbers are preferred for practical reasons. These savings may be accounted for in the following manner :—

(1) Regaining tangential losses.
(2) Reduction in resistance caused by stern post.
(3) Reduction in propeller suction, which may be explained by the reduction in revolutions when the contra-propeller is fitted.

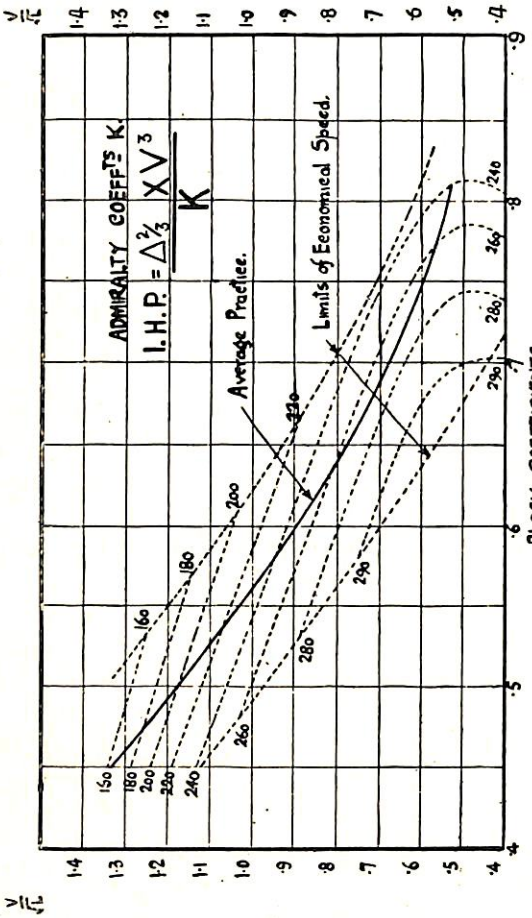
Savings of 15% in power are quite common where this device is fitted. It is also stated to help the steering. Items (2) and (3) may be regained by a body of symmetrical section in the propeller jet. For this purpose, several symmetrical stream line rudders, such as the Oertz and Flettner have been patented. The ordinary balanced rudder, by being made of the stream line form, can also regain some of this loss. They all undoubtedly improve the steering, although some doubts have arisen in regard to the Flettner rudder for deep-sea vessels. For river work, it has undoubtedly realised its claims. As regards twin-screws, so far it has been impossible to measure any favourable effect due to these rudders. We thus see that while the efficiency of twin screws may be improved by about 7% by properly designed struts and correct direction of rotation of propellers, a combination of contra-propeller and stream-line rudder in single-screw ships may effect a saving of well over 15%.

In conclusion, the author would draw the attention of the reader to what is known as the " Maier " form of framing, about which very little has been published so far, but it is reported several German firms are ordering vessels of this form. If the claims of those in the know are true, it will certainly revolutionise the science of ship design. From the meagre details published it seems to consist of a parallel middle body of about one-third the length and of an after and fore end of V frames with a rising line of keel from the parallel body. This form should certainly help the vessel to turn quickly, but how it will help to keep on a straight course is rather doubtful. It will be very interesting to see how the first full-sized vessel will behave at sea.

Finally, I would draw attention to the so-called corrugated ships. The inventors claim a considerable saving in power, but Mr. Baker expresses his doubts in regard to this, in fact stating he cannot see any superiority over the ordinary form. However, repeat orders have been placed, on the whole not a bad sign.

APPENDIX A.

Plate No. 57, taken from an article by Mr. Peter Doig, gives an exceedingly useful diagram from which the designer will be able to obtain a very good estimate of his horse-power, besides seeing whether his relationship between $\frac{V}{\sqrt{L}}$ and the block coefficient gives him an economical ship as defined by the heavy line of average practice. These admiralty coefficients have been calculated for 400 feet lengths and corrections will have to be made to their values for lengths of ships greater or less than this. The Table underneath the diagram gives these corrections.



Corrections to K for length.

100 feet, less	9 per cent.	300 feet, plus	1½ per cent.
200 ,, ,,	5 ,,	600 ,, ,,	3 ,,
300 ,, ,,	2 ,,	700 ,, ,,	4½ ,,
400 ,, ,,	0 ,,	800 ,, ,,	6 ,,

Limits $\frac{B}{L}$ ratio ·105 to ·140 $\frac{D}{B}$ ratio ·50 to ·30.

PLATE 57.

As it is usually necessary to approximate to the stability particulars early in the design, the following Table of coefficients, taken from the same article, will be found useful.

Table 16.

	P.C.	·52	·54	·56	·58	·60	·62	·64	·66	·68	·70	·72	·74	·76	·78	·80	·82	·84
	r	·823	·841	·860	·870	·880	·890	·890	·890	·890	·890	·890	·895	·903	·914	·925	·937	·948
k	L.C.B. 1% Ford.	·071	·0695	·069	·068	·0685	·0685	·0695	·0705	·073	·075	·077	·0785	·0795	·0805	·0815	·082	·0825
k	L.C.B. Amidships	·075	·0725	·0705	·069	·068	·068	·068	·070	·0725	·0745	·0765	·0775	·0785	·0795	·0805	·0805	·081
k	L.C.B. 1% Aft.	·0785	·075	·072	·070	·068	·068	·0685	·0715	·0705	·077	·079	·08	·08	·08	·08	·0795	·079

Note.—The above values have been obtained with Prismatics, varying as follows :—

P.C.	Cm.	$\frac{\text{Beam}}{\text{Draught.}}$
·5	·92	3·6
·6	·94	2·7
·7	·96	2·2
·8	·98	1·9

B.M. $= \dfrac{k\,B^2}{d\,C_m}$ where k is coefficient as given in tables.

B beam, d draught.

V.C.B. $= d\ (\cdot 833 - \cdot 333\ r\ C_m)$ r being obtained from table.

For arriving quickly at the necessary stability, the diagrams in the 1920 Shipbuilding Encyclopedia, published by the Marine Engineering and Shipping Age will be found most useful.

APPENDIX B.

Explanation of how to find Prismatic Coefficients, fore and aft, for standardised diagrams.

To find Prismatic Coefficient forward and aft :—

Suppose for example, ship 400 feet long, with centre of buoyancy 2·6 feet forward, and total prismatic coefficient ·750.

$$\frac{2\cdot 6}{400} = \cdot 0065\ \text{L forward, or } \cdot 0130\ \left(\frac{L}{2}\right)$$

Try ·765 forward and ·735 aft.

Reading from curve of locus of C.B. forward at ·765, Plate 38, we find C.B. to be ·3975 of $\frac{L}{2}$ forward. Similarly at ·735 we have ·3875 of $\frac{1}{2}$ L aft.

Find difference in moments :— ·765 × ·3975 = 3040875

·735 × ·3875 = 2848125

1·5 = 019275

$\dfrac{019275}{1\cdot 5} = \cdot 01285\ \left(\dfrac{L}{2}\right)$ forward, which is approximately correct.

An approximate rule, known as " Hoggs Rule," is as follows :—

$$\frac{\text{C.B. aft or forward + ·1\% of length}}{\text{half length}} =$$

amount to be added to or deducted from C_p.

In above example :—

$$\frac{2\cdot 6 + \cdot 40}{200} = \cdot 015.$$

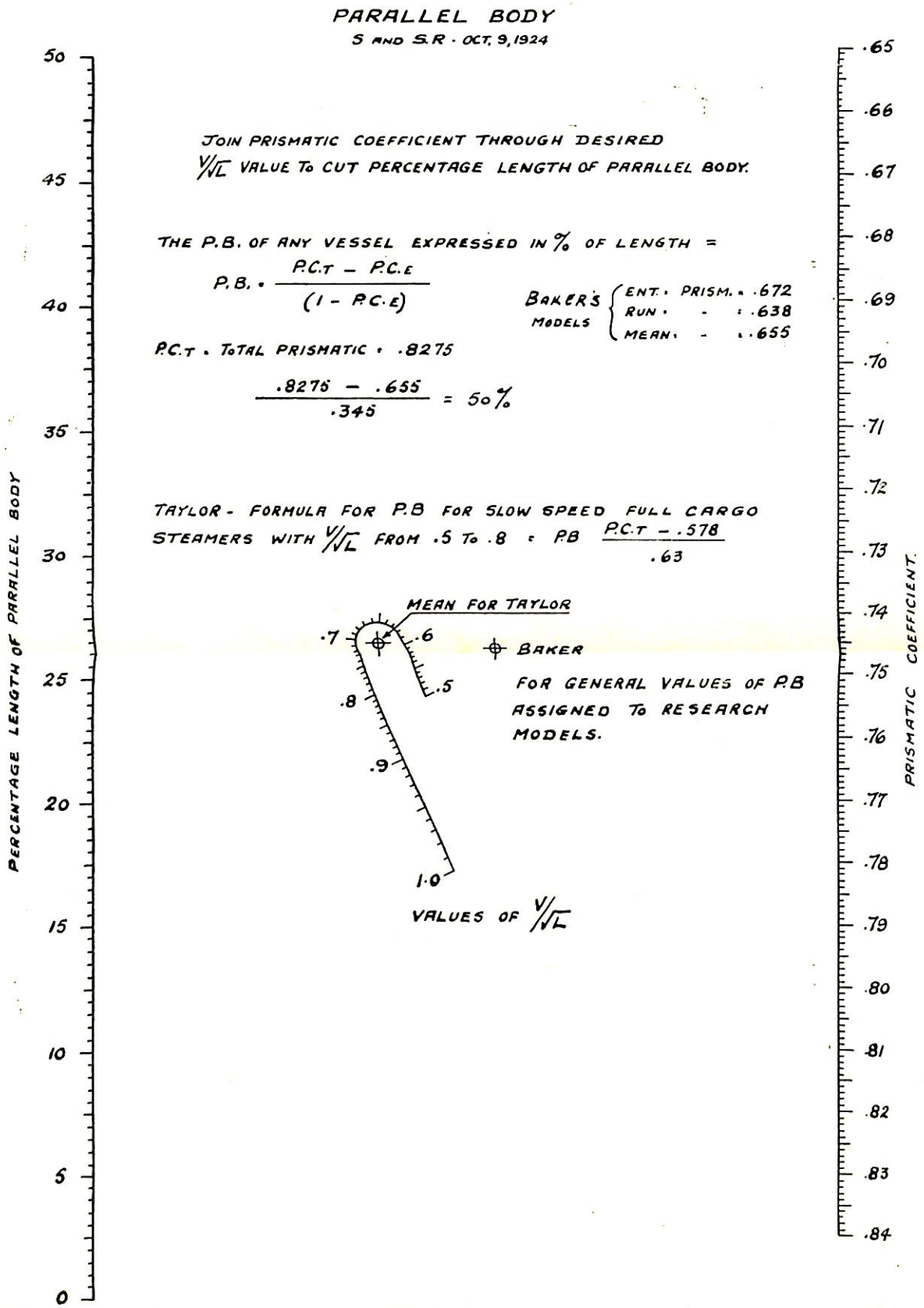
C_p forward = ·750 + ·015 = ·765.

C_p aft = ·750 — ·015 = ·735.

which is in this case almost identical.

APPENDIX C.

NOMOGRAPH FOR FINDING AMOUNT OF PARALLEL BODY.



APPENDIX D.

NOMOGRAM FOR DETERMINATION OF (S) VALUE

S AND S.R.- SEPT 18, 1924.

(S) = WETTED SURFACE OR SKIN CONSTANT

$(S) = .09346 \frac{W.S}{\Delta^{2/3}}$ Δ = DISPL^t IN TONS

THE CHART WAS DESIGNED TO EMBODY THE FORMULA $(S) = 3.6 + \frac{(M)}{2.1}$

(M) = THE LENGTH CONSTANT = $\frac{L}{\Delta^{1/3}} \times .3057 = 4.64$

EXAMPLE :-

VESSEL - L.B.P. = 176'-0" B.MLD = 32'-6" DRAFT MLD = 13'-3"

BLOCK COEFF. = .71

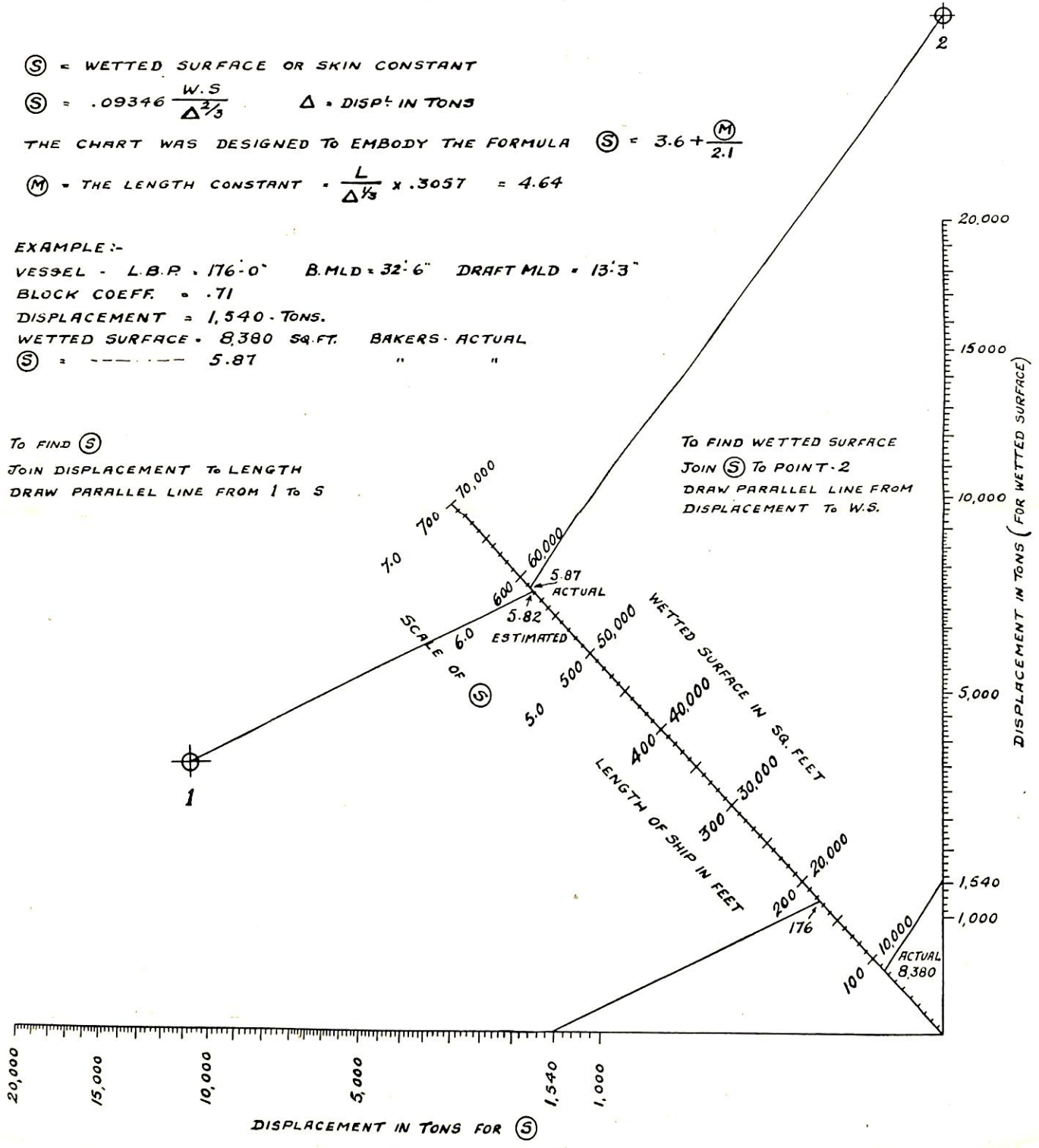
DISPLACEMENT = 1,540 - TONS.

WETTED SURFACE = 8,380 SQ.FT. BAKERS - ACTUAL

(S) = ---·-- 5.87 " "

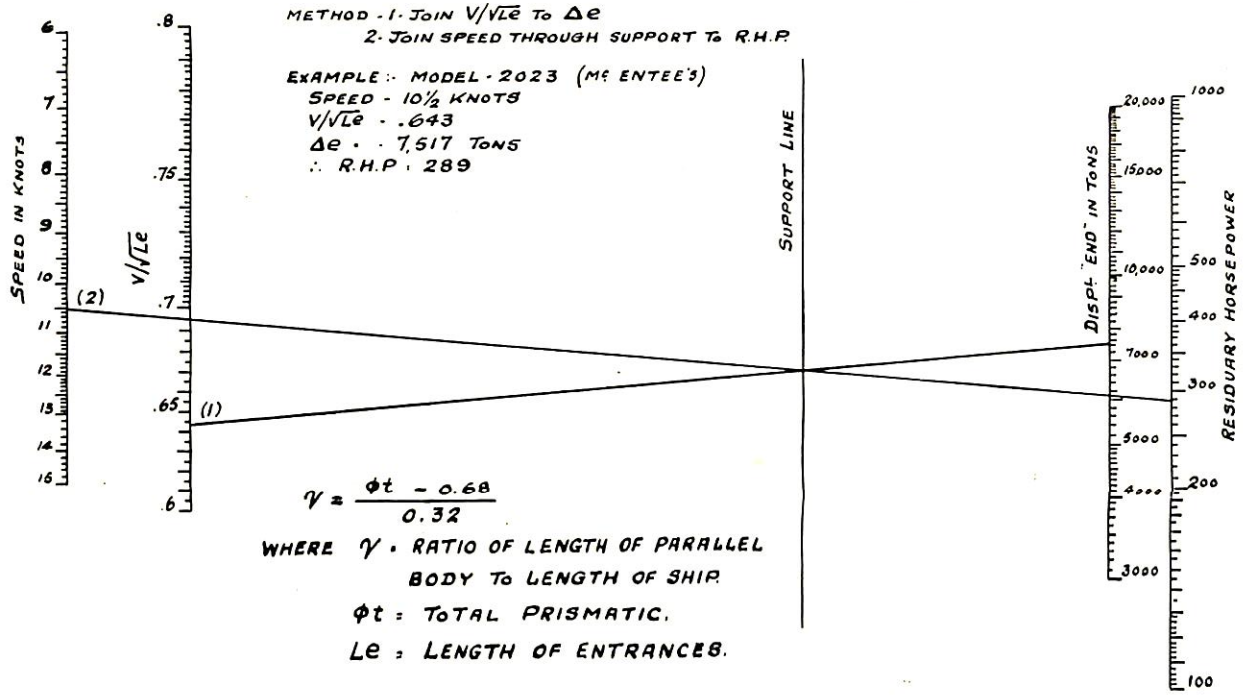
TO FIND (S)
JOIN DISPLACEMENT TO LENGTH
DRAW PARALLEL LINE FROM 1 TO S

TO FIND WETTED SURFACE
JOIN (S) TO POINT-2
DRAW PARALLEL LINE FROM
DISPLACEMENT TO W.S.



APPENDIX E

NOMOGRAM FOR THE ESTIMATION OF THE RESIDUARY HORSEPOWER OF FULL CARGO SHIPS.
MARINE ENGR + SHIPPING AGE
NOV. 1926
BY F McALISTER.


METHOD - 1. JOIN V/√Le TO Δe
2. JOIN SPEED THROUGH SUPPORT TO R.H.P
EXAMPLE :- MODEL - 2023 (Mc ENTEE'S)
SPEED - 10½ KNOTS
V/√Le - .643
Δe - 7,517 TONS
∴ R.H.P - 289
SPEED IN KNOTS
V/√Le
SUPPORT LINE
DISPL. "END" IN TONS
RESIDUARY HORSEPOWER
(1)
(2)
γ = φt − 0.68 / 0.32
WHERE γ = RATIO OF LENGTH OF PARALLEL BODY TO LENGTH OF SHIP
φt = TOTAL PRISMATIC.
Le = LENGTH OF ENTRANCES.

MODEL - 2023 - LENGTH - 400.0 FEET - BREADTH - 57.3' - DRAFT - 26.0' - DISPt 13,137 TONS. PRISMATIC COEFF. 0.788 - MIDSHIP SECTION COEFF. 0.987 - PARALLEL BODY 33.4 PERCENT AT 10½ KNOTS THE VESSEL IS STATED TO REQUIRE - 1080 - E.H.P.

HENCE, LENGTH OF PARALLEL BODY - 133.6 FEET, DISPt OF PARALLEL BODY - 5620 - TONS THUS THE "END" SHIP HAS A LENGTH OF 266.4' AND A DISPt OF 7517 - TONS.

THE $V/\sqrt{Le}$ IS $10.5/\sqrt{266.4}$ = 0.643 AND FROM THE NOMOGRAM THE R.H.P IS FOUND TO BE 289

THE WETTED SURFACE MAY BE ESTIMATED FROM THE WRITERS FORMULA,

$W.S. = 2.05\ L\left(\frac{B}{4}(1+\gamma) + D\right)$ L, B AND D HAVE THEIR USUAL SIGNIFICANCE.

SUBSTITUTING THE VALUES WE HAVE

$2.05 \times 400\left(\left(\frac{57.3}{4} \times 1.334\right) + 26.0\right)$ = 37,000 SQUARE FEET.

THE F.H.P IS $0.0030707 \times 0.0091 \times 37{,}000 \times 10.5^{1.83}$ = 802

THE TOTAL EFFECTIVE HORSE POWER IS THUS 289 + 802 = 1091, WHICH COMPARES FAVORABLY WITH THE TANK FIGURE OF 1080.